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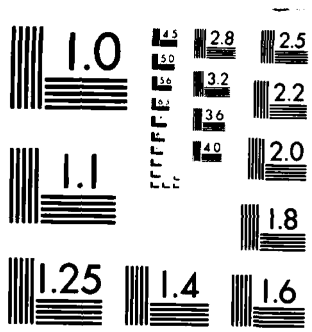


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DEFENSE LOGISTICS AGENCY

EMERGENCY PLANNING MODELS

THESIS

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# DEFENSE LOGISTICS AGENCY EMERGENCY PLANNING MODELS

THESIS

Presented to the Faculty of the School of Engineering

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In Partial Fulfillment of the

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Master of Science in Operations Research

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William R. Frazier, Jr.

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## Abstract

This research enhances the Defense Logistics Agency planning process by developing two emergency planning models. These models are macro-models of the inventory control point system and the depot system. If a natural disaster or sabotage destroyed an entire facility during peace time, these models would provide insight into what realignment actions would have to occur and the potential magnitude of the actions. The model results would be used in conjunction with other essential information in the decision making process.

Both models are formulated as linear programming models. The primary objective is to minimize the cost of realigning the systems. Both personnel and material resources are considered. The Northwestern University Multi-Purpose Optimization System is used to program the models. The sensitivity of the models is examined in detail.

# DEFENSE LOGISTICS AGENCY EMERGENCY PLANNING MODELS

## I. Introduction

### Background

The Defense Logistics Agency (DLA) manages over two million stocked and nonstocked consumable items for the Department of Defense. The Agency serves not only the Army, Navy, Air Force, and Marine Corps, but also the Coast Guard, the National Aeronautics and Space Administration (NASA), the General Services Administration (GSA), many other government agencies, and certain foreign governments through the Foreign Military Sales (FMS) program.

Materiel management and distribution are handled by six inventory control points (ICPs) and six primary depot activities. The six ICPs are: the Defense Construction Supply Center (DCSC) at Columbus, Ohio; the Defense Electronics Supply Center (DESC) at Dayton, Ohio; the Defense Fuel Supply Center (DFSC) at Cameron Station, Alexandria, Virginia; the Defense General Supply Center (DGSC) at Richmond, Virginia; the Defense Industrial Supply Center (DISC) at Philadelphia, Pennsylvania; and the Defense Personnel Support Center (DPSC) at Philadelphia, Pennsylvania. The six depot activities are: Defense Depot Mechanicsburg, Pennsylvania (DDMP), Defense Depot Memphis, Tennessee (DDMT), Defense Depot Ogden, Utah

(DDOU), Defense Depot Tracy, California (DDTC); a depot co-located with DCSC; and a depot co-located with DGSC.

The ICPs manage eight different commodity categories which are: construction (DCSC), electronics (DESC), fuel (DFSC), general (DGSC), industrial (DISC), clothing and textile (DPSC), medical (DPSC), and subsistence (DPSC). DCSC, DESC, DGSC, and DISC are known within DLA as the "hardware" centers.

The primary mission of an ICP is to act as the inventory manager for the commodity it is assigned. In this capacity, the ICP receives requisitions (i.e., electronic messages or paper forms requesting numbers of units of items), directs shipments to be made from storage sites, and replenishes inventories at storage sites by buying from commercial vendors. Each ICP, except DFSC and DPSC (subsistence), is under DLA's Standard Automated Materiel Management System (SAMMS) with its five subsystems, namely, distribution, requirements, technical, financial, and procurement. The distribution and requirement subsystems support the supply functional areas of an ICP by handling customer requisitions and assisting item managers in determining inventory levels and positioning stock at storage sites. The procurement subsystem supports the procurement functional area of an ICP by assisting buyers in purchasing supplies from commercial vendors. The technical subsystem supports the technical functional area by maintaining technical information on items for use in buying stock and assuring that the right items or legitimate

substitutions are shipped to customers. The financial subsystem supports the financial functional area by providing funds for inventory buys, maintaining financial records of all transactions, and providing an information base for budgeteers to prepare their budgets. In summary, an ICP consists of a number of skilled administrators and a computer system working as a wholesale distributor for consumable items used within the Department of Defense (DoD).

The primary mission of a DLA depot is to act as a storage site for wholesale supplies. A depot has four major functions: (1) the receipt of materiel, (2) the storage of materiel, (3) the care of materiel, and (4) the shipment of requisitioned supplies to DLA customers. The DLA depot system primarily uses the six DLA-owned depots in addition to facilities at the Navy Supply Center, Norfolk; the Navy Supply Center, Oakland; and the New Cumberland Army Depot. All stocked items in the system, except some DFSC-managed items which have specialized storage locations and some items in Service-owned depots, are stored in these nine facilities.

As the primary DoD manager of consumable items, DLA provides significant support to the Services. DLA accomplishes this support by means of a system of ICPs and depots located in various parts of the country. If a natural disaster (tornado, hurricane, earthquake, etc.) or sabotage were to destroy an ICP or depot, DLA would still need to render effective and efficient support, so that the Services could maintain their desired state of readiness.

Recent DoD exercises have shown that DLA would still be able to function in an emergency, but that response to customer demands would definitely decline. A major improvement would be the development of models that would show how resources and missions could be realigned if either an ICP or depot were no longer a part of the DLA Materiel Distribution System. These models would assist DLA logistics planners in providing for continuing operations in the event of the loss of an ICP or depot due to sabotage or some type of natural disaster. By giving planners the ability to study different policies such models would definitely play a significant role in the planning process. Current modeling and simulation capability cannot be used to address the problems associated with emergency planning. Without emergency planning models, DLA emergency planners have only their experience supported by available data to get them through the required realignment process. Emergency models could facilitate this process by relating the numerous factors which need to be considered and permitting analysis of options. The models could be run prior to or immediately after an emergency to show planners the problems involved in a particular emergency.

## Problem

The problem is to develop ICP and depot models that provide realignment solutions to different catastrophe situations. The DLA Materiel Management and Distribution System must

continue to serve its customers, even if one of its ICPs or depots can no longer function. The loss of an ICP or depot would cause major problems, but DLA would have to realign its resources and missions to continue its customer support. Only models can simultaneously consider all of the variables involved in such a realignment. Such models have not yet been created from the management information now available. The development of these models should greatly assist DLA commanders and logistics planners in the event of a catastrophe.

All requisitions are assigned to one of three issue priority groups (IPG). IGP I is for requisitions of items that are necessary for a primary combat unit to complete its mission. IPG II is for requisitions of items that are necessary for a primary combat unit to complete its mission without any limitations. IPG III is for requisitions of items that a non-primary combat unit or a training unit or a support unit needs in order to complete its mission. This category would include expendable items that are mission essential for non-combat units, as well as items that are not mission essential for any type of unit that are used in the daily operation of a unit. When an ICP receives a valid requisition for a stocked item, the ICP creates an MRO, which authorizes a depot to issue the item to the customer.

Two examples will illustrate the problem. In the first example, if the depot at Tracy were destroyed, its Material Release Order (MRO) processing function would have to be

carried out, under the current plan, by the Defense System Automation Center (DSAC) at Columbus, Ohio. Material scheduled for delivery would have to be redirected to Ogden or to a rented warehouse in the Tracy area or to another depot owned by the Federal Government. Issues of material would be made from another depot that stocks the same item or a commercial vendor on a direct vendor delivery (DVD) basis. Although these measures would handle the immediate problems associated with satisfying customer demand, they do not handle the long term problems of depot/customer assignment, depot capacity overload, and unique storage requirements. In the second example, if the ICP at Dayton, Ohio, were destroyed, under the current plan, its requisition processing function would have to be carried out by DSAC. The Defense Automated Addressing System (DAAS) would drop the ICP from the addressee listing and route those requisitions to DSAC. DSAC would process the requisitions that the automated system could handle, giving priority to IPG I and II requisitions and either produce an MRO or authorize a procurement from a commercial vendor. The items from the vendor could go directly to the customer or to a depot and then to the customer. All other requisitions would have to be processed manually. DSAC does not possess personnel with the skill and knowledge necessary to review requisitions. These requisitions would have to be reviewed by qualified personnel either at DCSC or another designated ICP. They would be processed only on an as time is available basis, except for those that have a

high priority. Again, these measures would provide for the early stages of an emergency but would not address the long term problems of reassigning item management and procurement to minimize the disruption and cost to the total system.

## Research Objective

The primary objective of this research project is to develop macro-level emergency planning models for realigning resources and missions in the event of the loss of an ICP or depot. Since they are macro-models, these planning models, will include only the primary activities and resources in the material distribution system. In order to develop the models, two main objectives need to be satisfied. The first one is to identify the pertinent factors affecting emergency planning and describe their effects on the system. In this first process, the essential ICP and depot activities in the current system must be identified initially. Then, the new activities generated as a result of the destruction of an ICP or a depot must be shown. Next, the alternatives available for accomplishing the workload generated by all the remaining activities must be developed and the resources needed to perform each alternative must be shown.

The second objective is to define an analytical framework which will provide, within realistic constraints, the best reallocation of resources and missions after an emergency and will define the shortfalls that would need to be considered in the planning process.

To satisfy these two main objectives, the following intermediate objectives need to be attained:

1. Determine the costs involved in realigning resources and missions in alternative scenarios;

2. Determine the facilities available for realigning ICP and depot missions;

3. Determine the primary major equipment items necessary to realign an ICP or depot mission;

4. Determine primary services (ADP, communications) necessary to realign an ICP or depot mission;

5. Identify the personnel skills and resources necessary to operate an ICP or depot in order to determine what would need to be transferred from the destroyed location to another location or developed in new personnel hired by alternative sites remaining in the system;

6. Determine the objective function for planners faced with the loss of an ICP or depot; and

7. Determine the constraints involved in realigning a lost ICP or depot.

## Limitations and Assumptions

The problem concerns the total destruction of an ICP or depot during peace time. The loss of one of these major facilities would have a significant impact on existing DLA operations and on the state of readiness of the Services. Each ICP manages and each depot stocks items that support major weapons systems. The items play a critical role in

keeping a weapon system in a fully mission capable status. If an ICP were lost, all current inventory management records would be lost, as well as the experience and expertise of the item managers. These factors would be quite significant if a high priority requisition were to come in from a deployed combat unit shortly after the disaster. Available resources would have to be used in order to satisfy this critical demand, but major delays would be caused by the lack of information. At the depot level the detrimental impact of a disaster on force readiness could be major. If no suitable substitute were available or if the production lead time was extensive for a given item, an item manager would have great difficulty in filling a high priority requisition for that combat unit. Any major delays in contracting would definitely be detrimental to the state of readiness.

A minor impact on readiness would occur because some of the consumable items used in the day-to-day operation of a base would not be available. If these items were not available for an extended period of time, the lack of the items could have a distinct impact on the readiness posture of a unit. However, every effort would be made to obtain suitable substitutes from either the public or private sector in order to avoid an adverse impact.

Additional problems would occur because of the loss of facilities, the loss of ADP capability, and the need for rapid funding for both new construction and acquisition of parts. With the loss of facilities, item managers would have

no place to work and incoming items would have no storage locations. With the loss of ADP capability, the entire requisitioning process would be disrupted. All current ICP inventory records would have been lost. At the depot all data used for automated storage and retrieval would be lost. Emergency funding would be required for both construction of new facilities and acquisition of new parts. Congress would probably readily authorize monies considering the emergency situation, but it would still take time to build new facilities and procure new parts. Even more time would be required to get the facilities into a fully operational status with all the necessary support equipment.

The overall goal for the planners and, therefore, in the models will be to minimize the disruption and cost to the materiel distribution system. In the process of reaching this additional goal, these limiting parameters or assumptions are employed:

1. Only the four hardware ICPs will be considered, since DLA fuels and personnel support ICPs are unique and could not be realigned within the other DLA ICPs.

2. Only the six DLA depots will be considered, since DLA stores the bulk of its materiel in its own depots and the loss of a Service depot would involve more than the realignment of DLA supplies.

3. The models will consider only the total destruction of a single ICP or a single depot.

4. Workload shifts will be accomplished to the extent possible within the current system before new capacities are developed.

5. Alternatives will be limited to realigning within existing ICPs or depots.

6. Specialized personnel, i.e., those having special skills, will be segmented according to their specific job series; such as, item managers, etc. All other personnel will be grouped together in a general command/support category.

7. Funds will be available to realign the system. The actual amount and source of such funds would, in reality, depend on statutory limitations, such as the funding limitations on military construction, but these legislative realities will not be considered in the planning models.

8. Data supporting the model must be readily available at DLA Headquarters because of the emergency scenario.

9. Item management is the same for items in each commodity.

10. Contracting is the same for items in each commodity.

11. Supplies to run an ICP or depot would be readily available at the backup or alternative locations and, therefore, are not considered. ICP supplies would include desks, chairs, and writing materials. Depot supplies would include crates, boxes, and pallets.

12. Customer demand rates are not affected by the loss of a depot or an ICP.

13. In the event an item has a long lead time, and all or almost all of the stock of that item has been destroyed, the demand will be satisfied either by a suitable substitute, an emergency contract with a qualified manufacturer, or local manufacture in a DoD-owned machine shop of a suitable replacement part.

14. Transportation costs from the depots to the customers are aggregated. All the outbound shipping costs are averages, since neither differences in commodities nor differences in Federal Supply Classes are considered. This assumption is valid, since the depot model is a macro-level model for use in planning.

Analysis Procedure

In performing the analysis, two objective functions have to be formulated: one for ICP activity; the other for depot activity. As the first step in this process, alternatives for accomplishing the activities of the destroyed site must be developed. Second, the significant resources required in order to perform each alternative need to be examined. As each alternative and the required resources are identified, expressions will be developed that will show how system performance will be degraded by the emergency. These expressions will then be combined into linear objective functions that will be optimized on a computer using mathematical programming algorithms. The available resources in each situation will be the constraints on the objective functions.

Catastrophe Planning Methodology

An ICP or defense depot could be eliminated at any time through sabotage or natural disaster. In spite of such a catastrophe, DLA must continue to process requisitions and purchase materiel in order to meet the demands of its customers.

A disaster could take any one of several different forms. An incident could result in an ADP outage of less than 12 hours or the loss of a building due to fire. This project is concerned with a catastrophic disaster (i.e., loss of an entire depot or an entire ICP facility). Such a loss would be a major disruption of the materiel distribution system and would require extensive planning and coordination to assure continuing mission accomplishment in spite of the realignment.

In planning for a realignment, budgetary limitations would have to be considered, especially in view of legal restrictions. But those limitations would be secondary to the reconstitution of the capability to accomplish the mission. It is assumed that DLA would have full DoD support in obtaining the funds necessary to continue its mission.

A number of short term adjustments would be in effect in the event of a catastrophe. High priority requisitions (IPG I and IPG II0 would continue to be filled either out of stock or by direct vendor deliveries. Warehouse space in the area of an eliminated depot could be leased in order to receive the items that had already been shipped by the vendors. Critical personnel at back-up locations could be

granted overtime to ensure that priority requisitions would continue to be processed. Personnel could be transferred, temporarily or permanently, to other locations in order to augment a particular skill. Commercial or military transportation would be made available to quickly move civilian and/or military personnel to back-up sites. These personnel could be used to set up an extended duty hour schedule, which in the case of the depots and certain ICP operations could be 24 hours per day, seven days per week.

However, the previous adjustments do not address the major problem to be resolved in a catastrophe. That problem is how to realign the missions of the remaining activities to include the mission of the destroyed activity. In the case of a depot, this means reassigning depot/customer support areas to assure that all DLA customers are supported by its depot system. In the case of an ICP, this means reassigning items to assure that all items assigned to DLA for management are indeed managed. Once the major decisions are made regarding realignment of missions, then all of the many decisions regarding individual customers, individual items, personnel actions, equipment and service requests, etc., can be made. Summarizing, in the event of catastrophic disaster to an ICP or depot, emergency planners must first answer the macro-question of mission realignment.

ICP Catastrophe Planning

Under the current plan, each ICP has a back-up site for the processing of requisitions. The primary back-up site for all ICPs is DSAC. The alternates are the other ICPs. After the disaster, the DAAS would drop the destroyed site from the addressee list for requisitions. All the requisitions would be sent to the appropriate back-up site for processing. No processing could begin until the back-up files were obtained from DLSC at Battle Creek; however, once these files were available, most requisitions could be processed by the automated system. IPG I and II requisitions would be handled first; IPG III requisitions would be processed on an as-time-is-available basis. In short, the current plan is to provide for continuing operations.

However, difficulties do exist with the current plan. For example, time is recognized as a limitation for two reasons. First, a computer can process only a certain number of requisitions in a 24-hour period. Unless additional ADP equipment was obtained, this limitation would continue, ensuring a backlog of IPG III requisitions. Second, item managers can handle only a finite number of requisitions, even if the number of available manhours was increased. When this factor is considered in addition to the problems involved with item managers working with unfamiliar items, it is apparent that these manual requisitions would also contribute to the backlog of IPG III requisitions. More fundamental issues are that the plan does not properly address

the constraints on an ICP's ability to absorb workload, the impacts of new workload, and the transfer of personnel from a lost ICP.

In order to address these problems, the ICP model includes five major activities:

1. item management,
2. procurement,
3. other ICP functions (e.g., technical services),
4. ADP support, and
5. telecommunications support.

In an emergency situation, all five of these activities will have to be accounted for since comprehensive inventory management would need to be performed by the realigned system. In addition, personnel transfer and provisions for office space would be new activities that need to be taken care of in a realignment plan.

Alternatives to accomplish these activities, include the entire transfer of the lost ICP activities to another ICP or the splitting of the lost ICP workload and the transfer of activities to multiple ICPs based on the split. These alternatives do not include use of commercially available office space because of the difficulty in incorporating these facilities into the DLA system. A mathematical model formulated to include all of the activities would determine the precise alternative.

Formulation of such a model is based on identifying and correctly relating the resources for accomplishing activities

under the alternatives. In this case, resources can be divided into five categories: personnel, equipment, facilities, supplies and materials, and money. The personnel resources are item managers, procurement specialists or buyers, and command/support personnel. Relationships that must be considered are the transfer or hiring of persons to fill the personnel resources required to manage the realigned items. The equipment resources are: (1) ADP hardware, (2) telephones, (3) telephone lines, and (4) digital communication lines. Since telephones and telephone lines are readily available at any location, they need not be considered. The capacities for ADP hardware and digital communication lines must be considered, so that they are not exceeded by realigned workloads. The supplies and materials resources are desks, chairs, and writing materials. Both would be readily available within a very short leadtime and, therefore, need not be considered.

The financial or money resources are in the form of numerous costs: (1) personnel salary and wage costs, (2) personnel transfer costs, (3) personnel hiring costs, and (4) the costs of additional capacities (i.e., office space, ADP, etc.). Personnel salary and wage costs are not considered, since those costs would be relatively the same regardless of the location(s) where workload is transferred. Overtime costs could be used, but are not considered in the formulation of the model. The function of an ICP would require additional personnel to be available during normal duty

hours to interface with other military organizations and contractors. Minor costs such as utility costs and supplies and materials costs would be excluded because they also would be similar regardless of gaining location(s). Inclusion of the other personnel and capacity costs in the objective function will be the basis for evaluating alternatives while other resources would define the feasibility of alternatives.

Depot Catastrophe Planning

Under the current plan, each depot has a back-up site for the processing of MROs. The primary back-up site for all depots in DSAC. The alternates are the other depots. After the disaster, the DAAS would drop the destroyed site from the addressee list for MROs. All MROs would be sent to the appropriate back-up site for processing; however, no processing could begin until the back-up files were obtained from DLSC at Battle Creek. Once these files were in place, MRO processing could start. High priority MROs would be taken care of first; lower priorities would be handled later. As was the case with the ICP plan, the current depot plan is to provide for continuing operations.

Difficulties exist with the depot plan. The number of warehouses would be the major limitation. Only a certain number of items can be picked, packed, and shipped, even if the workload is on a 24-hour per day basis. The freight docks are large enough to handle only a limited number of shipments, especially considering that shipments could not be made any

time of the day or night, seven days per week. Storage space is limited. The basic problem is the assignment of workload to back-up sites based on the capacities at those sites and the realignment costs.

In order to address this problem, the depot model includes seven activities:

1. receiving,
2. stowing,
3. picking,
4. packing,
5. shipping (outbound and intra-depot),
6. ADP support, and
7. telecommunications support.

In an emergency situation, all seven of these activities will have to be accounted for plus personnel transfer and space requirements.

The basic alternatives that would need to be considered to accomplish these activities are:

1. Outlining depot realignment by new geographical boundaries of customer responsibility for each depot.

2. Specifying depot realignment by new commodity assignments for each depot and outlining new depot boundaries.

Each depot has an assigned geographical area of responsibility. If a depot were eliminated from the system, the areas would have to be redefined to assure continuing customer support. After the catastrophe, one depot might gain responsibility for the entire area that had been served by

the destroyed depot, or two or more depots might split the responsibility. This alternative would only consider changing boundary lines; it would not consider changing commodity stockage policy. Within the distribution system, each depot stocks different combinations of commodities. When a depot is eliminated from the system, demands could be satisfied by realigning the assignment of commodities. If a commodity were stocked at only one depot, then that commodity could be assigned readily to another depot. If a commodity were stocked at more than one depot, then the available stock at the other depot or depots could be augmented. The decision could be to add stock to all depots remaining, or it could be to add stock to only particular depots. In either case, changing boundaries, as in the case of the first alternative, could also be a factor.

The alternatives include the use of commercially available warehouses. A mathematical model formulated to include all of the activities in a depot realignment would determine the precise alternative. Formulation of such a model is based on identifying and correctly relating the resources for accomplishing activities under the alternatives.

Just as was the case with the ICP catastrophe, these resources are divided into five categories: personnel, equipment, facilities, supplies and materials, and money. The personnel resources are: (1) receipt personnel, (2) stow personnel, (3) select personnel, (4) packing personnel, and (5) shipping personnel, including intra-depot transportation

personnel. Although the skills are different within these personnel categories, they do not require extensive special training and, therefore, can be lumped into a single personnel category. Relationships that must be considered are the transfer or hiring of persons to fill the personnel requirement of a transferred workload. The equipment resources are: (1) ADP hardware, (2) telephones, (3) telephone lines, (4) digital communication lines, (5) bin storage racks, and (6) mechanized materiel handling equipment (MMHE), including intra-depot transportation vehicles. Since telephones and telephone lines would be made available at any location, they are not considered. Only specialized MMHE will be considered. Major considerations are that the ADP hardware and digital communication line capacities are not exceeded by realignment workloads.

The facilities available are: (1) indoor storage space, (2) outdoor storage space, and (3) administrative space. Since outdoor space can be considered unlimited and administrative space is minor at a depot, only indoor space will be considered.

The supplies and materials available are: (1) desks and chairs, (2) writing materials, (3) pallets, and (4) packing materials. These items are readily available at any location and, therefore, are not considered.

The financial or money resources are in the form of numerous costs: (1) personnel salary and wage costs, (2) personnel transfer costs, (3) personnel hiring costs, and

(4) the costs of additional capacities (i.e., space, ADP, etc.). Personnel salary and wage costs are not considered since those costs would be relatively the same regardless of the location(s) where workload is transferred. Overtime costs are not considered. Minor costs such as utility costs and supplies and materials costs would be excluded because they also would be relatively the same regardless of gaining location(s). The costs will be the basis for evaluating alternatives, while the other resources would define the feasibility of alternatives.

## Format

Chapter II is a literature review that cites current research into resource allocation problems and distribution problems. The use of mathematical programming to resolve these problems is discussed.

Chapter III discusses the formulation of the two models. The foundations for the models and the rationale for the form of the models is addressed.

Chapter IV explains the compilation of data elements used in the models. The derivation of data elements used in the models and the identification of sources of data are presented.

Chapter V cites the results and the analysis of those results from the computations performed with the ICP model. Model sensitivity, model verification, and model validation are discussed.

Chapter VI presents the results and the analysis of those results from the computations performed with the depot model. Model sensitivity, model verification, and model validation are examined.

Chapter VII cites the conclusions and recommendations derived from the analyses of the ICP and the depot models. Lucrative areas for future research are addressed.

# II. Literature Review

The investigation into techniques for developing emergency planning models led to a review of problems in resource allocation, distribution systems, transportation systems, and assignment methods. The common factor involved in each of these problems is that they all are solved through the use of linear programming. Integer programming and mixed integer programming are closely related solution techniques. The conclusion is that a linear programming formulation is good for the emergency planning models for the ICP system and the depot system.

## Applied Research Review

Harrison created a system for planning facilities and resources in distribution networks (13). His system is a three-stage stochastic programming model that evaluates different management strategies, considering varying costs and population movements over an extended time horizon. The system can examine alternative locations for distribution points using both cost and demand information. The planning model itself has about 2000 variables and 300 equations. The route planning model has about 300 locations and 1200 customers. Because of the size of these models, a special matric generator had to be developed that would make data preparation easier and would allow solutions to be arrived at in a realistic time. The system had to perform three

functions. First, it had to determine the optimal distribution pattern from existing warehouses. Second, it had to evaluate alternative warehouse locations, considering both customer location and demand. Third, it had to show the effect on overall distribution policy of changing unit delivery costs, warehouse capacity restrictions, and customer demand patterns. The planning model was set up essentially in the form of the classical transportation problem, but it could be modified to handle nonlinear costs. Utilizing an expectation function, it becomes a full stochastic programming model that can take into account uncertainties in demand. Because of this structure, sequential solutions to the model can be calculated, depending on the scenario. Once the planning model is run, then the route planning model is used to find out the optimal customer calling sequence from a given depot. It is based on the concept that customers can be served at less cost by supplying them on a round trip instead of on separate trips. This planning system proved extremely successful, since it significantly decreased delivery and transport costs and increased customer service levels.

Eldredge developed a computer model for examining the elements of a distribution system (8). The elements included manufacturing plants, warehouses, demand points, and transportation routes. The basic problem is in the form of a transshipment problem. The objective is to determine a low-cost, high-service-capacity warehouse distribution

system. His model for optimizing distribution systems (MODS) uses a heuristic approach to solve the problem. The model was developed for an organization which distributes products throughout the United States. To keep the problem at a manageable level, demand had to be aggregated at the county level and potential warehouse points had to be limited. The model was structured to minimize cost for a specified minimum service level for all demand points. The costs considered were warehouse storage and handling costs, interest cost on inventory carried, state taxes, personal property taxes, income taxes, franchise taxes, cost of order processing, transmission equipment, administrative costs, and transportation costs.

In using MODS the first step is to generate the model inputs. The second step is to use the transportation algorithm to resolve the transshipment problem for each product category. The third step is the inclusion of warehouse fixed costs and the computation of measures of service level. The fourth step is to print management reports. The last step is the Modification-Elimination procedure. This procedure looks to see if an inactive warehouse should be brought into the solution. If such a warehouse is activated and only a set number of warehouses can be utilized, then on the basis of variable costs the procedure specifies which location should be eliminated. This procedure makes this method better than some others, because it allows an eliminated warehouse to return to the solution if it is more

economical, and it specifies a list of alternative warehouses for each warehouse, thereby limiting possible substitutes.

Thornley had to evaluate the Woolworth distribution system and recommend improvements (23). The problem had several aspects including the variety of the goods handled, levels of stocked items, requirements for direct delivery items, and numerous delivery frequencies. The only way to calculate an optimal solution would have been to create a large mathematical programming formulation. Since this formulation would have been quite difficult and expensive, she decided to use a proven computer program called DISCO. This program examined both flows and costs in the distribution system and could handle large numbers of supply and demand points. The use of this program took full advantage of the experience levels of the joint management and consultant team. The primary input to the program was a set of supply and demand points along with the associated quantities for each point. The distribution flow between areas served by depots was set in proportion to the supply and demand in those areas. Transport costs were calculated based on quantity and distance. Depot costs were derived from cost functions using depot throughput. Data collection was a significant effort for both supply and demand data. A sensitivity analysis was performed on all cost data. Several different depot strategies were evaluated using depots for both stocking

items and transshipment of items. The final solution was implemented by Woolworth.

Glover and his associates examined the significance of integrating production, distribution, and inventory (PDI) operations (12). Their computer-based PDI system has been used to study the benefit/cost impact of differing capital investments in both short-term and long-term planning decisions. Advanced network methodology was necessary to develop a system that could solve the problem in a reasonable amount of time on a computer. One especially interesting facet to the use of network methodology was that it makes the system easy to understand; thereby, facilitating the communication required in order to implement the solutions. The overall objective of the research was to develop a computer-based planning system that would integrate the three major segments of the decisions of the company. These components were the Supply Segment, the Storage and Customer Distribution Segment, and the Demand Segment. In the area of long-range planning, the PDI system has been used to determine the sizing and configuration of the distribution system. In the area of short-range planning, the PDI system examined resource allocation over a specified distribution center configuration.

The primary component of the PDI system is the Least Cost Distribution (LCD) model. This model is used to minimize variable production costs, transportation costs, transshipment costs, and inventory holding costs, subject to

demand constraints, supply constraints, throughput constraints, and shipping constraints. Because of the size of both the short-range and long-range problems (6000 equations, 35,000 variables), new computer codes had to be used to solve these large network/linear programming formulations. This code was critical because the model had to be run repeatedly in the decision making process. The success of this effort resulted in savings of millions of dollars to the company.

Murtagh and Niwattisyawong investigated a method for solving the multi-depot location-allocation problem by using large-scale nonlinear programming (19). Both the location of the depots and the amount shipped from each depot to each customer are variable. The goal is to minimize a nonlinear function describing the total distribution cost subject to some linear constraints. In order to solve the problem, they treat the location and allocation aspects simultaneously. The objective function represents the total transportation cost. The linear constraints state that the demands of each customer must be satisfied. An examination of the partial derivatives of the objective function reveals that the function is generally non-convex. Since it is non-convex, preprocessing of the problem data is required to find an initial estimate, because the solution obtained by a search procedure is highly dependent on where the search is initiated. They use the MINOS nonlinear programming system to solve the problem. The MINOS code handles

minimization problems with large sparse linear or nonlinear constraints. The solution methodology is essentially an extension of the revised simplex method of linear programming. Capacity constraints on the depots in the system can be added to the problem without changing the solution procedure. The problem could also be modified to have nonlinear constraints. This study showed that a method could be developed that would give a planner flexibility at a reasonable cost.

Erlenkotter explores a new way to resolve the uncapacitated facility location problem (9). The facilities are not restricted in size and are distributed among a fixed number of possible sites. The overall objective is to minimize the total cost of satisfying a certain number of demands from a fixed number of locations. The procedure he proposes is dual-based, and it initially involves a linear programming formulation with variable upper bound constraints. The solution of this problem is concerned with minimizing the difference between the primal and dual solutions by keeping the number of complementary slackness violations as low as possible. He develops both a dual ascent procedure and a dual adjustment procedure. The dual ascent procedure considers demand locations in ascending order in order to obtain a possible dual solution and a possible integer primal solution. The purpose of the dual ascent procedure is to determine whether or not the dual objective value can be improved. If an optimal integer solution is not found through the use of these two procedures, then the

branch-and-bound method is applied using the solutions developed by those procedures. Erlenkotter then shows how the theory can be put into effect using the DUALOC program. Application of this program confirmed the validity of his approach.

Kelly and Khumawala investigated a special case of the warehouse location problem (17). This problem is defined as a particular class of mixed integer programming problem usually concerned with physical distribution systems. In this problem, a limited number of possible warehouse sites are available, each one having a fixed cost and a form of operating costs. The warehouses have a maximum capacity. The distribution costs are a total of fixed costs, operating costs, and transportation costs. The goal is to minimize total distribution costs while satisfying the customer demand requirement. The three categories of constraints are warehouse capacity constraints, customer demand requirements, and indivisible fixed warehouse costs. The variable operating cost functions are nonlinear, continuous, and concave. The variable costs reflect economies of scale over the entire range of throughputs up to the maximum warehouse capacity. The solution method involves iteratively solving transportation problems. It takes into account the advantages of both the tangent line approximation and the chord approximation to the warehouse cost function. Only the previous solution has to be kept at each step in the solution process, thereby making storage requirements quite reasonable. The primary

advantage of this algorithm is that it is based on the concept of converging on the optimal solution instead of using enumeration.

Slowinski examined constrained resource project network scheduling, which can also be defined as minimizing project duration under fixed resource requirements and availabilities (21). The requirements for certain types of resources are fixed for the specified performing mode. The usage of resources is set at a specific level for each time period for the duration of the project. In the development of a real-world problem, three additional factors would have to be considered. First, each activity could have more than one possible performing mode. Second, resource limitations would need to be specified for total usage during each time period and for total consumption during the entire term of the project. Third, other desirable project performance criteria would need to be considered.

Slowinski assumes that each activity could be interrupted and then started again at a later time with no time penalty. Interruption is reasonable, because the cost is minimal when compared to the potential gain. Resources considered fall into three types: renewable, non-renewable, and double constrained (usage and consumption). Each combination of resources had a performing time for the activity. Both time and cost are considered in performance evaluation. Using linear programming, he developed two approaches to solving the problem. In the one-stage

approach, linear programming was used to solve the classical project network scheduling problem with unique activity performing modes. In the two-stage approach, the solution to the linear program is used as the input data to an algorithm for obtaining an optimal schedule. These two approaches can be applied to a significant number of resource allocation problems.

Sherali and Adams examined a way to resolve the discrete location-allocation problem (DLAP) using Benders' decomposition method (20). The location-allocation methodology is used to determine the least-cost way of both locating service facilities and satisfying all the demands of the customers. The problem they consider is discrete, because each production facility must be located on its own preselected site in a one-to-one correspondence. The costs included in the total annual cost are construction, production, and transportation. The problem is to minimize the total cost through the use of linear programming. The method they propose involves implicit enumeration of a mixed-integer program. The final solution uses the special structure of the problem in order to employ Dantzig-Wolfe's decomposition method. The structure concerns the fact that the DLAP is composed of an assignment problem and a transportation problem. Using sixteen reasonable size problems, they proved the efficiency of their proposed algorithm.

Hung and Rom use an alternating path basis in order to produce an efficient dual algorithm for the assignment

problem (16). An assignment problem has a network made up of origin nodes, destination nodes, and arcs that go from origin to destination. Their algorithm initially relaxes some constraints in order to arrive at a solution. Using alternating path bases, the violated constraints then are introduced into the relaxed problem. Through this method the relaxed problem always has an optimal solution. Shortest path algorithms are used to create the optimal alternating path basis. The alternating path concept is derived from the fact that a spanning tree can represent the basis in a network flow problem. Each time a violated constraint is enforced, a new optimal solution is obtained. The proof for this algorithm depends on finding an optimal alternating path basis to the relaxed problem and an optimal solution to the relaxed problem with a violated constraint enforced. During computational testing, their results compared favorably with the results obtained from other algorithms. The only weakness that was discovered was that the efficiency of their algorithm was not as good for sparse problems as it was for dense problems. This weakness is attributed to the fact that the computer code was written primarily for dense problems.

## Summary

This literature review yielded several fine examples of the application of mathematical programming. Each author devised an excellent technique to solve the problem he was

confronted with. The works of Harrison, Eldredge, Thornley, and Glover are particularly noteworthy because of the significant impacts they had on decisions made by top-level management. Since all these works are concerned with large distribution systems, they definitely relate to the DLA problem. They prove that linear programming is a valid technique for analyzing complex distribution systems. In the next chapter this technique will be applied to both the ICP problem and the depot problem.

## III. Model Formulation

### Modeling Techniques

Various techniques could be used in the development of a macro-model involving either centers or depots. In particular, linear programming is a mathematical programming technique which is used to solve many problems in the field of business, industry, medicine, and government and more importantly has been used to solve depot realignment problems within DLA. The technique did not receive widespread use until the development of computers which enabled analysts to solve large-scale problems, involving in some cases hundreds of decision variables. The basic format of the problem is expressed as:

maximize (or minimize)

$$Z = \sum_{j=1}^{n} c_j x_j$$

subject to

$$\sum_{j=1}^{n} a_{ij} x_j (\leq, =, \text{ or } \geq) b_i, \quad i=1,2,\ldots,m$$

$$x_j \geq 0, \quad j=1,2,\ldots,n$$

where $c_j$, $a_{ij}$, and $b_i$ are known constants for all i and j, and $x_j$ are nonnegative variables (22:35).

Using computer algorithms, problems formulated as linear programming models involving many decision variables and

many constraints can be solved. The underlying assumption of linearity in both the objective function and the constraints is the foundation for the solution process. Numerous problems can be expressed in a linear manner and then solved. In the development of emergency planning models, a linear objective function and linear constraints will be assumed.

Another technique which expands on linear programming is nonlinear programming. In actual systems, the only way to define the systems precisely is to depict the functional relationships between each component of the system. Such equations would accurately depict the system, but they would be quite difficult to solve because of their nonlinear character. Convex programming and quadratic programming are two types of nonlinear programming. In convex programming, the objective function, $f(x)$, is a concave function and all the constraint functions, $g_i(x)$, are convex functions. Quadratic programming as expressed in Hillier and Lieberman is in the form:

$$\text{Maximize} \quad \sum_{j=1}^{n} c_j x_j - \tfrac{1}{2} \sum_{j=1}^{n} \sum_{k=1}^{n} q_{jk} x_j x_k$$

subject to:

$$\sum_{j=1}^{n} a_{ij} x_j \leq b_i, \text{ for } i = 1, 2, \ldots, m$$

and:

$$x_j \geq 0, \text{ for } j = 1, 2, \ldots, n$$

where the $q_{jk}$ are given constants such that $q_{jk} = q_{kj}$ (14:725).

A method of solving nonlinear programming problems is to have an objective function and the constraint functions satisfy the Kuhn-Tucker Conditions. These conditions are stated in Hillier and Lieberman as:

Assume that $f(x)$, $g_1(x)$, $g_2(x)$, . . ., $g_m(x)$ are differentiable functions satisfying certain regularity conditions. Then:

$$x^* = (x_1^*, x_2^*, \ldots, x_n^*)$$

can be an optimal solution to the nonlinear programming problem only if there exist m numbers, $u_1 m\ u_2, \ldots, u_m$, such that all of the following conditions are satisfied:

1. $\frac{\partial f}{\partial x_j} - \sum_{i=1}^{n} u_i \frac{\partial g_i}{\partial x_j} \leq 0$

at $x_j = x_j^*$, for $j = 1, 2, \ldots, n$

2. $x_j^* \frac{\partial f}{\partial x_j} - \sum_{i=1}^{m} u_i \frac{\partial g_i}{\partial x_j} = 0$

3. $g_i(x^*) - b_i \leq 0$ for $i = 1, 2, \ldots, m$

4. $u_i(g_i(x^*) - b_i) = 0$ for $i = 1, 2, \ldots, m$

5. $x_i^* \geq 0$ for $j = 1, 2, \ldots, n$

6. $u_i \geq 0$ for $i = 1, 2, \ldots, m$ (14:723-724)

Comprehensive computer algorithms have been developed for solving the nonlinear problem. This ares is becoming

more significant, since many real world problems cannot be accurately depicted in a linear form.

Two linear programming concepts are of particular interest in relation to the DLA problem. The first one is the classical transportation problem which has the form:

Minimize $$Z = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij}$$

subject to

$$\sum_{j=1}^{n} x_{ij} = s_i, \text{ for } i = 1, 2, \ldots, m \text{ (supply)}$$

$$\sum_{i=1}^{m} x_{ij} = d_j, \text{ for } j = 1, 2, \ldots, n \text{ (demand)}$$

and

$$x_{ij} \geq 0, \text{ for all } i \text{ and } j \text{ (14:112-113)}$$

where

$i$ = index for sources, $i = 1, 2, \ldots, m$

$j$ = index for destinations, $j = 1, 2, \ldots, n$

$x_{ij}$ = number of units distributed from source i to destination j

$c_{ij}$ = cost per unit distributed from source i to destination j

$s_i$ = supply of units at source i

$d_j$ = demand in units at destination j

The second one is the fixed-charge problem, an integer linear programming problem which has the form:

$$\text{Minimize} \qquad z = \sum_{i=1}^{m} \left(\sum_{j=1}^{n} c_{ij}x_{ij} + f_i y_i\right)$$

subject to

$$\sum_{i=1}^{m} x_{ij} \geq b_j \qquad j = 1, 2, \ldots, n$$

$$\sum_{j=1}^{n} x_{ij} \leq a_i y_i \quad i = 1, 2, \ldots, m$$

$$x_{ij} \geq 0$$

$$y_i = )0, 1), \text{ for all } i \quad (22{:}23).$$

where

$i$ = index for plants, $i = 1, 2, \ldots, m$

$j$ = index for customers, $j = 1, 2, \ldots, n$

$x_{ij}$ = amount manufactured at plant i for customer j

$c_{ij}$ = cost of producing a unit at plant i and shipping it to customer j

$y_i$ = 1 if a plant is constructed at site i; 0 otherwise

$f_i$ = fixed investment cost of constructing a plant i

The fixed-charge problem is a specific form of the mixed integer linear programming problem which is:

$$\text{Maximize} \qquad z = \sum_{j=1}^{n} c_j x_j$$

subject to

$$\sum_{j=1}^{n} a_{ij}x_j \leq b_i, \; i = 1, 2, \ldots, m$$

$$x_j \geq 0$$

$$x_j \text{ integer, } j \in I \subset [1, 2, \ldots, n] \qquad (22:145)$$

where

$i$ = index for constraints

$j$ = index for decision variables

$x_j$ = decision variables

$a_{ij}$ = coefficients of decision variables in constraints

$b_i$ = upper limits of constraints

$c_j$ = coefficients of decision variables in objective function

The decision variables may be coded so that if an activity is included in the solution, its value is one, but if it is not included, its value is zero.

In summary, the solution methods to the emergency planning problem are all derivations of the linear programming concept. Either the transportation problem or the fixed-charge problem could be modified to fit the ICP system or the depot system.

Model Selection

In formulating objective functions, the primary concern is maintaining the capability to accomplish the mission. The mission could be continued in two ways, both assuming that many personnel were not killed in the disaster. First, if the total area around the facility were devastated by a natural catastrophe, then the mission could only be accomplished through total realignment. Second, if the damage was done

only to the DLA and not to the surrounding area of sabotage, the mission could possibly just be relocated to a Government-owned facility or a commercial facility close to the DLA facility. The Government-owned facility would definitely cost less, but a distinct time lag would exist in both cases. Even though the manpower would be available, all the necessary ADP and telecommunications equipment would not be at either location. Both situations could occur, but the macro-models in this research consider only the first case, since the second case involves modeling the capabilities of individual facilities, which is not within the scope of this research.

Quantifying the ability to accomplish the mission is a difficult task. In wartime it can be defined by wins and losses. In peacetime no simple measure exists. Maintaining peace is quite valuable, but cannot be measured. Cost is often a good measure in business and industry, but not necessarily in defense. Given the fact that this study deals with a peacetime scenario, a measure of effectiveness had to be used that would include both mission accomplishment and deterrence. In this situation, cost was deemed an appropriate measure, since it would take into account both the peacetime desire to keep costs low and the mission requirement of satisfying demand. By serving customers around the world at the lowest cost, the DLA mission would be fulfilled, in spite of the loss of an ICP or a depot.

An in-depth review of both the ICP problem and the depot problem reveals that both problems are essentially realignment problems. A realignment problem is a variation of the fixed-charge problem. In the normal realignment problem, all facilities remain in the system and resources are reallocated to create the most efficient distribution system. All system facilities and resources are available to use in the accomplishment of the mission. If a facility is closed, it will be closed because the best possible realignment shows that the facility is not necessary for mission accomplishment.

In this study, resources are realigned because one facility is destroyed. The workload of the destroyed location is distributed among the remaining facilities. The remaining facilities will have their primary resources augmented so that they can absorb the additional workload, assuming facilities will operate at maximum capacity and minimum possible cost.

Because these problems are quite similar to the fixed-charge problem, this application of linear programming was selected as the method for solving the problem.

In the process of realignment, the depot and the ICP situations are resolved separately. In the ICP situation, if one ICP is destroyed, then the workload could be split among the three remaining ICPs. The items could be equally apportioned, but the workload would probably not be. One site would probably get more high demand items than another.

Between the time that the item management was split and the time that the remaining ICPs gained additional manpower and equipment, requisitions in ICP III would need to be filled only on an as-resources-are-available basis. If instead of basing the division on items, it were based on requisitions, a similar problem would exist. A split of workload based on requisitions would probably mean an uneven split in the numbers of items. Since the requisitions at a given point in time do not totally reflect the item characteristics of the transferred items, the workload in the long term could be totally different from that at the time of the catastrophe. At the time of the disaster, two items could have the same number of requisitions, but the annual demand could be 100,000 for one item and 10,000 for the other item. Some personnel would have to be transferred and hired initially to satisfy immediate requirements, but in the long term, as the system stabilizes, additional personnel would have to be transferred or hired.

Space permitting, probably the most efficient solution in the long term would be to transfer all of the functions of the destroyed ICP to another ICP. This solution would be quite beneficial since a fully trained nucleus of skilled personnel would be in one location. Assuming military construction funds are made available, one ICP can take on the entire workload in the long term, but, in the short term, the workload would have to be split because of the facility constraints, and certain inefficiencies would have to be accepted.

Another consideration would involve the criticality and end item application of the items concerned; one ICP might get items that have numerous IPG I and IGP II requisitions and another ICP might have only a few mission essential items. Workload would be affected in different ways; one ICP would have more requisitions requiring immediate processing and another ICP would have more requisitions that would need to be put out to an IPG III backlog file for later processing. In spite of the fact that it is assumed that item management skills are the same for all items, a learning curve would still exist, since item characteristics and uses are not all the same.

The greatest initial impact would be in the areas of telecommunications and ADP. Additional digital communication lines, telephone lines, and computer hardware would be required. Until additional equipment could be acquired and put into operation, the production schedule for the SAMMS reports would have to change in order to minimize the backlog of requisitions by making additional computer time available for requisition processing. The SAMMS reports unique to an ICP would be suspended temporarily in order to gain additional processing time. The daily SAMMS updates would need to be accomplished on a delayed cycle, in order to accommodate the data on the additional items. The original processing schedule could be resumed once additional equipment was obtained and put into operation.

Augmenting the digital communication system and the telephone communication system can be relatively easy. Given the availability of equipment, compatible with that already used in the DLA system, the telephone company would probably rapidly install the necessary lines, since the situation would be a genuine defense emergency that would demand immediate attention. The greatest delay would definitely be caused by the acquisition of the additional computer hardware. The primary component would be the disk storage capacity. The back-up files from DLSC could not be utilized unless adequate storage space is available. The mainframes can probably handle the additional required processing.

In the depot situation, if one depot is destroyed, then the workload would have to be split among the five remaining depots. Because of stockage policy and geographic areas of responsibility, the actual increase in workload at each depot will depend on the NSNs assigned to each depot; all depots do not stock all NSNs. A high demand item will definitely have a greater impact on the increase in workload than a low demand item. Personnel would have to be reassigned based on the workload at the time of the catastrophe. The number of NSNs assigned is not as significant as the workload associated with those items. For example, a depot could gain 100 items that could get 100,000 MROs per year, or it could gain 100 items that could get only 1,000 MROs per year.

Stow workload will increase because of all the additional procurements made to replace the stock lost at the eliminated depot. This increase in workload would also be dependent on the item characteristics of those items assigned to each depot. For example, a depot could gain 100 items that all require bin storage, or it could gain 100 items that require a mix of bin and bulk storage. The necessary personnel, equipment, and storage space would be different in each case. As in the case of picking and packing, stow requirements would not stabilize for several weeks or in some cases, months because of the production leadtime for the items assigned. As the system stabilizes, additional personnel would be transferred or hired.

In this depot problem, the primary critical factor is storage space. As long as suitable storage space is available, a facility can continue to receive material. When a facility no longer has that space, either additional space has to be constructed or the incoming material must be stored at another location. Trained personnel are a desirable resource, but not a necessity since the required basic skills would be readily available in the labor force in the vicinity of every depot. As long as a small group of trained personnel were available to train new personnel, a depot could continue to function, even though the lack of training would cause some inefficiency. The need for communications and ADP equipment would be an initial problem; however, if the space were available and if the situation were an

emergency, the necessary equipment would probably be procured within a relatively small time frame. The only concern would be that the equipment would have to be compatible with the other equipment used by the DLA communications system.

## ICP Model

The ICP model measures the cost of realigning the ICP system after a catastrophe. The objective function is to minimize this cost of realignment. This cost has seven components:

1. cost of additional ADP equipment
2. cost of additional digital communication circuits
3. cost of additional office space units
4. cost to hire personnel
5. cost to transfer personnel
6. penalty cost associated with hiring item managers
7. penalty cost associated with hiring buyers

Each component is related to a major activity that is affected at the ICP's gaining workload because of the disaster.

Ten constraints bound the resources available to the ICP system. These constraints are:

1. Item constraint. All items managed by the destroyed ICP must continue to be managed.

2. ADP constraint. The gaining ICPs must have enough ADP processing capability to handle management of the additional items.

3. Digital communications constraint. The gaining ICPs must have enough digital communications capacity to handle management of the additional items.

4. Space constraint. The gaining ICPs must have enough administrative space for the transferred and hired personnel.

5. Personnel constraint. The total number of transferred and hired personnel in the system must be greater than or equal to the number of personnel authorized at the destroyed ICP.

6. Personnel transfer constraint. The number of personnel transferred must be less than or equal to the total number of personnel authorized at the destroyed ICP.

7. Personnel hiring constraint. The number of personnel who can be hired at an ICP is less than or equal to a specified percentage of the total number of personnel authorized at an ICP.

8. Item manager/buyer constraint. The ratio of item managers to buyers at the lost ICP will remain the same at the gaining ICPs.

9. Buyer/general personnel constraint. The ratio of buyers to the general personnel category will remain the same at the gaining ICPs.

10. Item manager constraint. The number of item managers transferred and hired will be greater than or equal to the number of item managers at the destroyed ICP.

## Mathematical Formulation of ICP Model

Notation

Subscripts

j = ICP facility

k = functional area (1 = item manager, 2 = buyer, 3 = general)

Variables

$adp_j$ = number of additional ADP units purchased for $ICP_j$

$d_j$ = number of additional digital communication circuits installed at $ICP_j$

$n_j$ = number of office space units added at $ICP_j$

$o_{jk}$ = personnel transferred to $ICP_j$ in area k

$p_{jk}$ = personnel hired at $ICP_j$ in area k

$Z_j$ = items transferred from lost ICP to $ICP_j$

Constants

aac = additional ADP capacity per additional unit of ADP equipment

adc = cost of additional communications circuits

asu = additional space per added space unit

$cac_j$ = current excess ADP capacity of $ICP_j$

ccp = cost of acquiring ADP equipment

cd = cost of acquiring digital communications circuit

$cdc_j$ = current excess digital communications capacity at $ICP_j$

$cp_{jk}$ = current number of persons in area k at $ICP_j$

$cpc_k$ = current number of persons in area k at lost ICP

$ct_j$ = cost to transfer a person to $ICP_j$

$hir_k$ = cost to hire a person in area k

isp = space required per person

itm = total items managed at lost ICP

$pby_j$ = penalty cost because of need to augment procurement staff at $ICP_j$

$pim_j$ = penalty cost because of need to augment item management staff at $ICP_j$

$prh_k$ = percent of current personnel in area k at gaining ICP used to set a ceiling on the number of persons who can be hired

$prt_k$ = percent of current persons in area k at lost ICP willing or able to transfer

ra1 = ratio of persons in area 1 (item managers) to persons in area 2 (buyers) at lost ICP

ra2 = ratio of persons in area 2 (buyers) to persons in area 3 (command/support) at lost ICP

$rsc_j$ = cost to add an office space unit at $ICP_j$

$sc_j$ = space available at $ICP_j$

ufp = ratio of the number of item managers to the number of items managed at the lost ICP

vfa = ADP utility factor

vfd = digital communications utility factor

Problem

Minimize

$$\sum_j (adp_j * ccp + d_j * cd + n_j * rsc_j + (\sum_k p_{jk} * hir_k)$$

$$+ (\sum_k o_{jk}) * ct_j + pim_j * p_{j1} + pby_j * p_{j2})$$

Subject to

$$\sum_j Z_j = (itm)$$

$$Z_j * vfa \leq cac_j + adp_j * aac \text{ for every } ICP_j$$

$$Z_j * vfd \leq cdc_j + adc * d_j \text{ for every } ICP_j$$

$$(\sum_k (o_{jk} + p_{jk}) * isp \leq sc_j + asu * n_j \text{ for every } ICP_j$$

$$\sum_j (o_{jk} + p_{jk}) \geq cpc_k \text{ for every area } k$$

$$\sum_j o_{jk} \leq prt_k * cpc_k \text{ for every area } k$$

$$p_{jk} \leq prh_k * cp_{jk} \text{ for every } ICP_j \text{ area } k$$

$$o_{j1} + p_{j1} = (ra1) * (o_{j2} + p_{j2}) \text{ for every } ICP_j$$

$$o_{j2} + p_{j2} = (ra2) * (o_{j3} + p_{j3}) \text{ for every } ICP_j$$

$$ufp * Z_j \leq o_{j1} \text{ for every } ICP_j$$

Depot Model

The depot model measures the cost of realigning the system after a catastrophe. The objective function is to minimize this cost of realignment. This cost has eight components:

1. cost of shipping commodities to customers
2. cost of transferring personnel
3. cost of hiring personnel
4. cost of additional ADP equipment
5. cost of additional digital communications circuits
6. cost of additional indoor storage space units
7. cost of additional storage bins
8. cost of additional mechanized material handling equipment.

Ten constraints bound the resources available to the depot system. These constraints are:

1. Demand constraint. The system must satisfy all demands from all customers.

2. Commodity constraint. The tons shipped out of each depot is less than or equal to the tons of each commodity that are shipped out of each depot according to the commodity shipping restriction pattern.

3. Customer constraint. The tons shipped out of each depot to each customer is equal to the total demand from each customer if the depot has no customer shipping restriction.

4. ADP constraint. The gaining depots must have enough ADP processing capability to handle management of the additional workload.

5. Digital communications constraint. The gaining depots must have enough digital communications capacity to handle management of the additional workload.

6. Bin storage constraint. The gaining depots must have enough bin storage capacity to be able to store the additional items.

7. Mechanized material handling equipment constraint. The gaining depots must have enough mechanized material handling equipment available to be able to handle the storage of additional items.

8. Storage space constraint. The gaining depots must have enough indoor storage space available to be able to store the additional items.

9. Personnel constraint. The number of personnel available in the system will be adequate to handle the additional workload.

10. Personnel transfer constraint. The number of personnel in the system willing or able to transfer will be equal to a percentage of the personnel available from the destroyed depot.

## Mathematical Formulation of Depot Model

Notation

Subscripts

$i$ = commodity

$j$ = depot

$k$ = customer

Variables

$adp_j$ = amount of ADP units added to depot $j$

$bin_j$ = number of additional bins required at depot $j$

$d_j$ = amount of digital communications circuits added to depot $j$

$mhe_j$ = number of mechanized material handling equipment (MMHE) added to depot $j$

$ph_j$ = number of persons hired at depot $j$

$pt_j$ = number of persons transferred to depot $j$

$sp_j$ = amount of additional indoor storage space units required at depot $j$

$x_{ijk}$ = tons of commodity $i$ shipped from depot $j$ to customer $k$

Constants

$aac$ = additional ADP capacity per additional unit of ADP equipment

$adc$ = additional digital communications units per circuit

$asp$ = additional space available per additional storage unit

$c_{ijk}$ = outbound transportation cost of shipping commodity i from facility j to customer k

$cac_j$ = current excess ADP capacity at depot j

$cbc_j$ = current number of bins at depot j

$cbn$ = cost of acquiring a bin for storage

$ccp$ = cost of acquiring ADP equipment

$cd$ = cost of acquiring digital communications circuits

$cdc_j$ = current digital communications capacity at depot j

$cf_j$ = cost of acquiring MMHE for depot j

$ch$ = cost to hire a person

$cmc_j$ = current MMHE capacity for depot j

$cpc_j$ = total number of excess personnel available at depot j

$cs_j$ = cost of additional purchased or rented indoor storage space units required at depot j

$csc_j$ = maximum amount of indoor storage space available at each depot

$ct_j$ = cost to transfer a person

$dem_{ik}$ = tons of demands of commodity i from customer k

$M_{ijk}$ = customer restriction number equal to 0 if depot j restricted from shipping commodity i to customer k; total demand from customer if depot j not restricted

$N_{ij}$ = commodity restriction number equal to 0 if commodity i restricted from depot j; total tons shipped of commodity if commodity i not restricted

pa = personnel available and willing to be transferred from destroyed depot

$ufa_i$ = ADP utility factor for commodity i

$ufb_i$ = bin utility factor for commodity i

$ufd_i$ = communication utility factor for commodity i

$ufm_i$ = MMHE utility factor for commodity i

$ufp_i$ = personnel utility factor for commodity i

$ufs_i$ = space utility factor for commodity i

Problem

Minimize

$$\sum_i \sum_j \sum_k c_{ijk} * X_{ijk} + \sum_j (ct * pt_j * ch * ph_j$$

$$+ ccp * adp_j + cd * d_j + cs_j * sp_j$$

$$+ cbn * bin_j + cf_j * mhe_j)$$

Subject to

$$\sum_j x_{ijk} = dem_{ik} \text{ all demand must be met}$$

$$\sum_k x_{ijk} \leq N_{ij} \text{ for every restriction}$$

$$x_{ijk} \leq M_{ijk} \text{ for every restriction}$$

$$\sum_i \sum_k (x_{ijk} * ufa_i) \leq cac_j + aac * adp_j, \text{ for every depot } j$$

$$\sum_i \sum_k (x_{ijk} * ufd_i) \leq cdc_j + adc * d_j, \text{ for every depot } j$$

$$\sum_i \sum_k (x_{ijk} * ufb_i) \leq cbc_j + bin_j, \text{ for every depot } j$$

$$\sum_i \sum_k (x_{ijk} * ufm_i) \leq cmc_j + mhe_j, \text{ for every depot } j$$

$$\sum_i \sum_k (x_{ijk} * ufs_i) \leq csc_j + asp * sp_j, \text{ for every depot } j$$

$$\sum_i \sum_k (x_{ijk} * ufp_i) \leq cpc_j + pt_j + ph_j, \text{ for every depot } j$$

$$\sum_j pt_j = pa$$

Summary

The linear programming formulation of both the ICP problem and the depot problem is a major step forward in the development of emergency planning. These formulations consider significant factors in the process of realignment after a catastrophe. The next step is the compilation of the data for use in the models. The following chapter discusses the derivation of the data elements and the identification of the sources of data.

# IV. Data Compilation

## Data Collection

In an actual situation, DLA will not receive prior notification of an imminent catastrophe. The data collected will have to be the data available to the Headquarters in a timely manner. Under these circumstances, the data would already have to be at the Headquarters in the form of either printed reports or as data elements in the Management Information System maintained by the Comptroller. In order to simulate the actual use of both models, the data were collected expeditiously from sources available at the Headquarters. Some of the data were not in the precise form desired for the models, but it was readily convertable. Other data were based on the experience and expertise of members of the DLA Headquarters staff. Some data elements were not available at all. The sources of data are in Appendix A. The data elements are in Appendix B.

## ICP Factor Calculation

ADP Utility Factor. The ADP utility factor is an indicator of the ADP requirement at an ICP. The factor is equal to the amount of disk storage used at an ICP divided by the number of items managed at an ICP. This type of factor was selected because the amount of disk storage is directly proportional to the number of items managed. In general, the larger the number of items, the greater the number of

requisitions submitted, and the higher the amount of disk storage required to process those requisitions.

Digital Communications Utility Factor. The digital communications utility factor is an indicator of the communications requirement at an ICP. The factor is equal to the number of message units processed at an ICP divided by the number of items managed at an ICP. This is a reasonable relationship since the larger the number of items managed, the greater the amount of message traffic involved in the management of those items. This factor is not used in running the model, because digital communications capacity is not perceived by telecommunications personnel as a significant constraint on the problem at this time.

## Depot Factor Calculation

ADP Utility Factor. The ADP utility factor is an indicator of the ADP requirement at a depot. The factor is equal to the amount of disk storage used at a depot divided by the weight of the material shipped by the depot. This type of factor was selected because the amount of disk storage is directly proportional to the weight of the material that is shipped. In general, the greater the total weight of the material shipped, the larger the number of MRO's processed, and the greater the disk storage space required in order to process those release orders.

Digital Communications Utility Factor. The digital communications utility factor is an indicator of the

communications requirement at a depot. The factor is equal to the number of message units processed at a depot to the weight of the material shipped by the depot. This relationship is reasonable, because the greater the total weight of all material shipped, the greater the amount of message traffic generated in the shipment of that material. In general, if the total weight shipped increases, then the number of items shipped increases, which means a corresponding rise in the number of shipping documents produced. This factor is not used in running the model, since digital communications capacity are not seen as a significant constraint on the problem at this time by telecommunications personnel.

Bin Utility Factor. The bin utility factor is an indicator of the bin requirement at a depot. For each commodity, the total number of bins in use at a depot is divided by the total weight shipped from that depot. Ideally, one of the staff offices would have a number for the amount of bin type storage units in use at each depot, but if that figure is not available, then some representative sample could be developed. A number specifically relating to the use of bins, such as the weight of material stored in bins, would be desirable, but in this macro-problem it would not be necessary. The weight of outbound shipments does indicate the workload at a given depot, even though the amount of stored material would have been better. The shipping weight information is available, and it does produce a ratio that relates the bin requirement to the depot workload, though

the shipped weight would be less than the stored weight. The ratio does express the fact that a certain number of bins are used in a depot system that ships a certain amount of material. This bin factor is not incorporated into the running of the model at this time, because no representative sample of the number and type of bins at a depot could be obtained at the Headquarters.

Space Utility Factor. The space utility factor is an indicator of the space requirement at a depot. For each commodity, the total amount of space in use at a depot is divided by the total weight shipped from that depot. Space in this problem is in terms of square feet of indoor storage area. Space could directly relate to weight of material stored, but those data are not readily available. Since this is a macro-problem, and since the input data is precise only for the point in time it is drawn, the relationship does not have to be an exact measure. All that is necessary is that the relationship show in general terms how storage space is utilized. The weight of stored material is usually greater than the weight of material shipped. However, the outbound material is an indicator of material that was stored. Since the weight of ourbound shipments can be extracted from available reports, this weight is used in setting up the ratio. This ratio does provide a valuable link between storage space utilization and depot output.

MMHE Utility Factor. The MMHE utility factor is an indicator of the MMHE requirement at a depot. For each

commodity, the total amount of specialized MMHE in use at the depot is divided by the total weight shipped from that depot. The workload relationship is not direct; however, MMHE does play an integral role in both the storage and retrieval of items for shipment. Since this relationship does exist, this factor is definitely a valid indicator, even though it is not a precise measure. The factor is not used in running the model, because no representative sample of the amount of specialized MMHE could be readily obtained at the Headquarters.

<u>Personnel Utility Factor</u>. The personnel utility factor is an indicator of the personnel requirement at a depot. For each commodity, the total number of people assigned to a depot is divided by the total weight shipped from that depot. This factor is not a precise workload measure, but it does relate the number of personnel assigned to the outbound shipments. Even though all personnel are not involved in outbound shipments, they are all involved either directly or indirectly in the production of that final product of a depot, the outbound shipment. For this reason, this factor is viewed as an appropriate indicator for this type of macroproblem.

## ICP Penalty Cost Calculations

<u>ICP Item Manager Penalty Cost</u>. When one ICP is destroyed by a catastrophe, the workload at the remaining ICPs will increase. Some fully qualified item managers will transfer

to augment the staff at the gaining ICPs, but most of the personnel will probably not transfer. People need to be hired to supplement the existing staff. These people need training in order to develop the skills required for item management. This training, even though it is necessary, definitely does detract from mission accomplishment.

DLA has a funded supply availability goal of 90 percent. The DLA policy is to assume that the skills of its item managers will be able to improve on this goal by 2 percent; thereby, making the attainable availability goal 92 percent. The training requirement will have an adverse effect on the ability of the staff to make that 2 percent improvement. An increase in supply availability is proportional to an increase in the safety level investment. This safety level investment is the foundation for the penalty cost.

In developing the penalty cost, the fact that the 2 percent improvement relates to a specific dollar value can be used as a measure of effectiveness of the item management staff. Training requirements lower the effectiveness of the staff and lower the dollar value invested in improvement of the supply availability goal. The 2 percent improvement will no longer be an attainable goal. This decreased dollar value can, therefore, be used as a way of showing the adverse impact on DLA of the catastrophe. The investment is included in the model as a penalty cost since it is evidence of the negative impact of the disaster.

Mathematical Formulation

$$PIM = SD - SD^*$$

$$= SD - \frac{SD * NMSAD}{MSAD}$$

$$= SD - \frac{SD * (MSAD - MSAD * f_T)}{MSAD}$$

$$= SD - \frac{SD * (MSAD - MSAD\ (1 - \frac{Total\ Hr - Training\ Hr}{Total\ Hr}))}{MSAD}$$

$$= SD - \frac{SD * MSAD - MSAD + MSAD\ (\frac{Total\ Hr - Training\ Hr}{Total\ Hr}))}{MSAD}$$

$$= SD - \frac{SD * (MSAD\ (\frac{Total\ Hr - Training\ Hr}{Total\ Hr}))}{MSAD}$$

$$= SD - SD * (\frac{Total\ Hr - Training\ Hr}{Total\ Hr}))$$

$$= \frac{(SD)(Total\ Hr) - (SD)(Total\ Hr) + (SD)(Training\ Hr)}{Total\ Hr}$$

$$PIM = \frac{SD\ (Training\ Hr)}{Total\ Hr}$$

where:

$SD$ = Safety level dollars

$SD_{IM}$ = Safety level dollars per item manager

$IM_{ICP}$ = Number of item managers at each ICP

$f_T$ = Training hours as a percent of total hours available

SD* = New safety level dollars

MSAD = Mean supply availability deviation due to good item management, 2%

PIM = Item manager penalty cost

NMSAD = New mean supply availability deviation due to good item management

ICP Buyer Penalty Cost

When one ICP is destroyed by a catastrophe, the workload at the remaining ICPs will increase. Some fully qualified contracting and procurement specialists will transfer to augment the staff at the gaining ICPs, but most of the personnel will probably not transfer. People need to be hired to supplement the existing staff. These people need training in order to develop the skills required for contracting and procurement. This training, even though it is necessary, definitely does detract from mission accomplishment.

DLA has funding allocated to support the demand during the administrative leadtime. This leadtime will increase after a catastrophe. The amount of administrative leadtime is proportional to the skills of the contracting and procurement specialists. The training requirement definitely does adversely effect the ability of the staff to efficiently process procurement requests. In order to satisfy demands immediately after the disaster, stock will be issued that would normally have been used to satisfy the leadtime demand.

In developing the penalty cost, note that the administrative leadtime has both an institutional component and a controllable component. The institutional component includes elements such as a statutory requirement that certain contracts be open for bids for a minimum of 30 days. The controllable component is the actual time that the buyer uses in processing procurement documentation. The value of the controllable component differs for large and small purchases. For large purchases, the component is estimated at 8.5 percent of the time; for small purchases, the component is estimated at 13.2 percent of the time. These percentages are multiplied by the percent of DLA purchases in the small (95 percent) and large (5 percent) categories to compute the amount of the administrative leadtime investment that is caused by the controllable component of the administrative leadtime. This figure is the penalty cost, since it identifies the investment. The penalty cost is a way of measuring the adverse impact of the added training on the system.

Mathematical Formulation

$$PBY = NALT\$ - ALT\$$$

$$= \frac{ALT\$ * (NALTF)}{ALTF} - ALT\$$$

$$= \frac{ALT\$ * (ALTF + ALTF * f_T)}{ALTF} - ALT\$$$

$$= \frac{ALT\$ * (ALTF + ALTF * (1 - \frac{Total\ Hr - Training\ Hr}{Total\ Hr}))}{ALTF} - ALT\$$$

$$= \frac{ALTF * (ALTF + ALTF - ALTF(-\frac{Total\ Hr - Training\ Hr}{Total\ Hr}))}{ALTF} - ALT\$$$

$$= ALT\$ * (2 - (\frac{Total\ Hr - Training\ Hr}{Total\ Hr})) - ALT\$$$

$$= 2\ ALT\$ - ALTR - ALTR\ (\frac{Total\ Hr - Training\ Hr}{Total\ Hr})$$

$$= ALT\$ - \frac{(ALT\$)(Total\ Hr) - (ALT\$)(Training\ Hr)}{Total\ Hr}$$

$$PBY = \frac{(ALT\$)(Total\ Hr) - (ALT\$)(Total\ Hr) + (ALT\$)(Training\ Hr)}{Total\ Hr}$$

$$PBY = \frac{(ALT\$)(Training\ Hr)}{Total\ Hr}$$

where:

ALT$ = Dollars invested to cover demand during administrative leadtime

$f_T$ = Training hours as a percent of total hours available

NALT$ = New administrative leadtime dollars

ALTF = Fraction of total leadtime demand investment required by administrative leadtime

NALTF = New fraction of total leadtime investment required by new administrative leadtime

PBY = Buyer Penalty Cost

## Summary

The data elements for the models were obtained solely from sources at DLA Headquarters. This method of collection was used because in an emergency the data must be available readily for planners and decision makers. Some data elements could be used directly by the models. Other data elements were used in the calculation of factors and penalty costs. In Chapter V and VI the ICP problem and the depot problem are analyzed by using the compiled data in the models.

# V. ICP System Analysis

Using the ICP model, analyses were performed based on the destruction of each ICP by a catastrophe. Two different solution methods were applied to each of the four scenarios after making the four baseline runs. This chapter will discuss the application of the model, the implementation of the model, and the results obtained from the model.

## Model Application

Once the model was formulated and the data elements were compiled, as noted in the last two chapters four baseline runs were made by eliminating each of the four ICP locations, one at a time. After these four baseline runs were nade, two additional runs were made for each ICP. One shows the effects of requiring that some personnel be transferred from the destroyed area to gaining ICP locations. The second shows the effects of requiring that the ADP and the space variables have integer values. This run also illustrates the use of an integer programming algorithm. The results can be compared to show the unique characteristics of each scenario.

## Model Implementation

The four versions of the model were run in the MPOS form shown in Appendix C. These runs produced the base line for the additional runs. The REGULAR algorithm was used to solve the problem in each case. The BBMIP algorithm was

used when both ADP and space were integer values. Personnel variables could have been designated as integer, but they were not. The actual numbers of personnel hired and transferred probably will vary from the calculated numbers depending on the desires and abilities of the individuals concerned and on the judicious use of overtime. The calculated numbers would be used only for macro-planning purposes. ADP was selected because a partial disk drive could not be procured. Space was selected because even if a fraction of a building were constructed, it might be more cost effective to build the entire facility, considering both architectural and construction costs.

Results From Model

DCSC Eliminated. The results of the base line run are shown in Table 1. All three remaining ICP locations gained items with DESC picking up the most, then DISC, then DGSC. These figures agree with the intuitive concept of the solution, since DESC and DISC have costs that are close in value and much less expensive than DGSC. Both DESC and DISC hire up to the limit of 50 percent of their workforce in the command/support category. DISC also hires up to the limit on the number of buyers. Space and ADP costs are not different for each location, so they do not play a major role in the solution process. DGSC gains items as a last resort, since it is more expensive to hire personnel there. The maximum number of IM personnel and buyer personnel are transferred,

TABLE 1

DCSC Eliminated-Transfers Optional

Items Gaines

| | |
|---|---|
| DESC | 153995.20 |
| DISC | 140043.20 |
| DGSC | 80671.60 |

Space Added

| | |
|---|---|
| DESC | 1.64 |
| DISC | 1.49 |
| DGSC | .87 |

Personnel Hired

| | |
|---|---|
| DESC-IM | 73.92 |
| DESC-Buyer | 112.71 |
| DESC-Cmd/Sup | 883.00 |
| DISC-IM | 67.22 |
| DISC-Buyer | 128.00 |
| DISC-Cmd/Sup | 803.00 |
| DGSC-IM | 2.26 |
| DGSC-Buyer | 90.05 |
| DGSC-Cmd/Sup | 469.00 |

Personnel Transferred

| | |
|---|---|
| DESC-IM | 0.0 |
| DESC-Buyer | 56.82 |
| DESC-Cmd/Sup | 0.0 |
| DISC-IM | 0.0 |
| DISC-Buyer | 26.18 |
| DISC-Cmd/Sup | 0.0 |
| DGSC-IM | 37.00 |
| DGSC-Buyer | 0.0 |
| DGSC-Cmd/Sup | 0.0 |

ADP Units Added

| | |
|---|---|
| DESC | 4.16 |
| DISC | 3.78 |
| DGSC | 2.18 |

Total Cost

67,972,720.85

Iterations

31

because of the comparatively low cost of transferring people, especially in the case of IM personnel at DGSC. The other resources are allocated to agree with the assignment of personnel.

When the problem is set up so that 20 percent of the personnel at DCSC must be transferred, the results change as shown in Table 2. DISC now gains the most items followed by DESC, then DGSC. DISC hits the hire ceiling on buyer command/support personnel. DISC adds all of the buyer personnel and most of the command/support personnel who are transferred. DGSC again picks up all the transferred IM personnel. These results are expected because the costs at DISC are less than the costs at the other locations.

Table 3 lists the results when ADP disk drives and space units must be integers and when 20 percent of the personnel at DCSC must be transferred. These results are quite similar to those in the prior problem. DISC gains the most items. DISC hires as many buyer personnel as it is allowed. DISC accepts all the transferred command/support personnel. The differences occur because of the integer requirement. DISC would take on additional personnel, but it would require another complete building that would drive the total cost above the optimal level. DGSC is still the most expensive location.

Table 4 shows the cost percentages for all three situations. As expected, space is the largest component of total cost. Personnel hires, personnel transfers, and ADP follow

TABLE 2

DCSC Eliminated-Transfers Required

| Items Gaines | | Space Added | |
|---|---|---|---|
| DESC | 107090.33 | DESC | 1.14 |
| DISC | 190536.33 | DISC | 2.04 |
| DGSC | 77083.33 | DGSC | .82 |

| Personnel Hired | | Personnel Transferred (.2) | |
|---|---|---|---|
| DESC-IM | 51.40 | DESC-IM | 0.00 |
| DESC-Buyer | 117.90 | DESC-Buyer | 0.00 |
| DESC-Cmd/Sup | 478.01 | DESC-Cmd/Sup | 136.04 |
| DISC-IM | 92.00 | DISC-IM | 0.00 |
| DISC-Buyer | 128.00 | DISC-Buyer | 83.00 |
| DISC-Cmd/Sup | 803.00 | DISC-Cmd/Sup | 295.96 |
| DGSC-IM | 0.00 | DGSC-IM | 37.00 |
| DGSC-Buyer | 84.86 | DGSC-Buyer | 0.00 |
| DGSC-Cmd/Sup | 441.99 | DGSC-Cmd/Sup | 0.00 |

| ADP Units Added | | Total Cost |
|---|---|---|
| DESC | 2.89 | 79,995,056.14 |
| DISC | 5.14 | |
| DGSC | 2.08 | Iterations |
| | | 40 |

TABLE 3

DCSC Eliminated-Integers Required

| Items Gained | |
|---|---|
| DESC | 111111.11 |
| DISC | 185185.19 |
| DGSC | 78413.70 |

| Space Added | |
|---|---|
| DESC | 2.00 |
| DISC | 2.00 |
| DGSC | 1.00 |

| Personnel Hired | |
|---|---|
| DESC-IM | 53.33 |
| DESC-Buyer | 116.43 |
| DESC-Cmd/Sup | 637.10 |
| DISC-IM | 89.43 |
| DISC-Buyer | 128.00 |
| DISC-Cmd/Sup | 636.28 |
| DGSC-IM | .64 |
| DGSC-Buyer | 86.33 |
| DGSC-Cmd/Sup | 449.62 |

| Personnel Transferred (.2) | |
|---|---|
| DESC-IM | 0.00 |
| DESC-Buyer | 5.89 |
| DESC-Cmd/Sup | 0.00 |
| DISC-IM | 0.00 |
| DISC-Buyer | 77.11 |
| DISC-Cmd/Sup | 432.00 |
| DGSC-IM | 37.00 |
| DGSC-Buyer | 0.00 |
| DGSC-Cmd/Sup | 0.00 |

| ADP Units Added | |
|---|---|
| DESC | 3.00 |
| DISC | 5.00 |
| DGSC | 3.00 |

Total Cost

89,638,656.40

Iterations

117

TABLE 4

DCSC Eliminated Cost Percentages
Percent of Total Cost*

| Costs | .2 Transfers Optional | .2 Transfers Required | ADP and Space Required Integers |
|---|---|---|---|
| ADP | 2 | 2 | 2 |
| Space | 57 | 48 | 54 |
| Hires | 36 | 30 | 26 |
| Transfers | 5 | 21 | 19 |

* Percentages do not always add up to 100 because of rounding

in that order. The cost component for transfers increases when transfers are required. ADP is the same cost percentage in all three cases.

Sensitivity analysis shows that the model is quite sensitive to the input values. Table 5 shows the sensitive cost coefficients. Table 6 shows the sensitive right-hand-side constants. An input value was judged sensitive if a variance of plus or minus ten percent would change the solution when 20 percent transfers were required. The sensitive cost coefficients are for command/support personnel hires, ADP disk drives, space units, and certain transfers to DISC and DESC. In the cases where the cost cannot even increase one dollar, the coefficients are extremely sensitive. The most sensitive constraints are those governing the number of items managed by DCSC and the number of command/support personnel required by the system to make up for the loss of DCSC. The number of command/support personnel needed by the system is equal to the number of command/support personnel assigned to DCSC. Any presentation of these results would have to cite this sensitivity to the input values.

Table 7 shows what happens if the cost of transferring command/support personnel to DESC increases by one dollar. Table 8 portrays what happens if the cost of hiring command/support personnel at DCSC increases by one dollar. In both situations it was required that 20 percent of the personnel from DCSC be transferred. The major item of interest is

TABLE 5

DCSC Eliminated-Sensitive Coefficients

| Variable | Coefficient | Restricting Bound Upper | Restricting Bound Lower |
|---|---|---|---|
| Cmd/Sup hires-DESC | 1793. | None | 1793. |
| Cmd/Sup hires-DISC | 1793. | 1793. | None |
| Cmd/Sup hires-DGSC | 1793. | 1793. | None |
| ADP added-DESC | 125000. | 125000. | None |
| ADP added-DISC | 125000. | None | 125000. |
| ADP added-DGSC | 125000. | 125000. | None |
| Space added-DESC | 9600000. | 10109000. | 9350200. |
| Space added-DISC | 9600000. | 9849800. | None |
| Space added-DGSC | 9600000. | 10531000. | 9091300. |
| Buyer transfers-DISC | 30000. | 32420. | None |
| Cmd/Sup transfers-DESC | 30000. | 30000. | 29535. |
| Cmd/Sup transfers-DISC | 30000. | 30465. | 30000. |

TABLE 6

DCSC Eliminated-Sensitive Constants

| Constraint | Right-Hand-Side Constant | Restricting Bound Upper | Restricting Bound Lower |
|---|---|---|---|
| Items managed | 374710. | 375830. | None |
| Cmd/Sup required-system | 2155. | 2192. | 2151. |
| IM transfers required | 37. | None | 33.90 |
| Buyer transfers required | 83. | None | 75.90 |
| Buyer hire-DISC | 128. | None | 120.90 |
| IM/Item ratio-DESC | 0. | .54 | None |
| IM/Item ratio-DGSC | 0. | .54 | None |

TABLE 7

DCSC Eliminated-DESC Transfers ($30001)

| Items Gained | | Space Added | |
|---|---|---|---|
| DESC | 107090.33 | DESC | 1.14 |
| DISC | 190536.33 | DISC | 2.04 |
| DGSC | 77083.33 | DGSC | .82 |

| Personnel Hired | | Personnel Transferred (.2) | |
|---|---|---|---|
| DESC-IM | 51.40 | DESC-IM | 0.00 |
| DESC-Buyer | 117.90 | DESC-Buyer | 0.00 |
| DESC-Cmd/Sup | 614.05 | DESC-Cmd/Sup | 0.00 |
| DISC-IM | 92.00 | DISC-IM | 0.00 |
| DISC-Buyer | 128.00 | DISC-Buyer | 83.00 |
| DISC-Cmd/Sup | 803.00 | DISC-Cmd/Sup | 295.96 |
| DGSC-IM | 0.00 | DGSC-IM | 37.00 |
| DGSC-Buyer | 84.86 | DGSC-Buyer | 0.00 |
| DGSC-Cmd/Sup | 305.95 | DGSC-Cmd/Sup | 136.04 |

| ADP Units Added | |
|---|---|
| DESC | 2.89 |
| DISC | 5.14 |
| DGSC | 2.08 |

Total Cost

79,995,056.14

Iterations

41

TABLE 8

DCSC Eliminated-DISC Hires ($1794)

| Items Gained | | Space Added | |
|---|---|---|---|
| DESC | 107090.33 | DESC | 1.14 |
| DISC | 190536.33 | DISC | 2.04 |
| DGSC | 77083.33 | DGSC | .82 |

| Personnel Hired | | Personnel Transferred (.2) | |
|---|---|---|---|
| DESC-IM | 51.40 | DESC-IM | 0.00 |
| DESC-Buyer | 117.90 | DESC-Buyer | 0.00 |
| DESC-Cmd/Sup | 614.05 | DESC-Cmd/Sup | 0.00 |
| DISC-IM | 92.00 | DISC-IM | 0.00 |
| DISC-Buyer | | DISC-Buyer | 83.00 |
| DISC-Cmd/Sup | | DISC-Cmd/Sup | 432.00 |
| DGSC-IM | 0.00 | DGSC-IM | 37.00 |
| DGSC-Buyer | 84.86 | DGSC-Buyer | 0.00 |
| DGSC-Cmd/Sup | 441.99 | | |

| ADP Units Added | |
|---|---|
| DESC | 2.89 |
| DISC | 5.14 |
| DGSC | 2.08 |

Total Cost

79,995,723.10

Iterations

41

that, even though the basic feasible solution is different, as expected, the total cost is essentially the same. Therefore, these solutions are reasonable alternative solutions. Only one solution is mathematically optimal, but in reality that solution may not be the most practicable, especially since many factors not included in the model would play important roles in the decision making process.

DESC Eliminated. In a similar fashion when DESC is eliminated, the results of the three runs are in Tables 9, 10, and 11; the cost percentages are in Table 12; and the sensitivity results are in Tables 13 and 14. Several interesting points were made by these runs. DGSC was excluded from all solutions because of the high cost of hiring personnel. DISC hires as many people as it can, but it is restricted by the hiring limitation on command/support personnel. In the two cases where transfers are required, DISC gains more items because of its low hiring cost. When integer values are not required, DISC gains are limited by the hiring ceiling on IM personnel and command/support personnel. When integer values are required, DISC gains are limited by the fact that both ADP disks and space units must be integers. The cost percentages emphasized that space units are the largest component of total cost. The sensitivity analysis showed that the model was very sensitive to the values of the input parameters. The optimal solution would change with only a minor variation in some of the cost coefficients. A one-dollar increase would make a difference in

TABLE 9

DESC Eliminated-Transfers Optional

Items Gained

| | |
|---|---|
| DISC | 374853.84 |
| DGSC | 0.00 |
| DCSC | 446645.16 |

Personnel Hired

| | |
|---|---|
| DISC-IM | 94.09 |
| DISC-Buyer | 63.22 |
| DISC-Cmd/Sup | 803.00 |
| DGSC-IM | 0.00 |
| DGSC-Buyer | 0.00 |
| DGSC-Cmd/Sup | 0.00 |
| DCSC-IM | 70.72 |
| DCSC-Buyer | 135.64 |
| DCSC-Cmd/Sup | 962.00 |

ADP Units Added

| | |
|---|---|
| DISC | 4.50 |
| DGSC | 0.00 |
| DCSC | 5.36 |

Space Added

| | |
|---|---|
| DISC | 1.47 |
| DGSC | 0.00 |
| DCSC | 1.77 |

Personnel Transferred

| | |
|---|---|
| DISC-IM | 0.00 |
| DISC-Buyer | 50.00 |
| DISC-Cmd/Sup | 0.00 |
| DGSC-IM | 0.00 |
| DGSC-Buyer | 0.00 |
| DGSC-Cmd/Sup | 0.00 |
| DCSC-IM | 42.00 |
| DCSC-Buyer | 0.00 |
| DCSC-Cmd/Sup | 0.00 |

Total Cost

54,276,961.35

Iterations

39

TABLE 10

DESC Eliminated-Transfers Required

Items Gained

| | |
|---|---|
| DISC | 507527.63 |
| DGSC | 0.00 |
| DCSC | 313971.37 |

Space Added

| | |
|---|---|
| DISC | 2.00 |
| DGSC | 0.00 |
| DCSC | 1.23 |

Personnel Hired

| | |
|---|---|
| DISC-IM | 128.00 |
| DISC-Buyer | 104.03 |
| DISC-Cmd/Sup | 803.00 |
| DGSC-IM | 0.00 |
| DGSC-Buyer | 0.00 |
| DGSC-Cmd/Sup | 0.00 |
| DCSC-IM | 36.81 |
| DCSC-Buyer | 94.83 |
| DCSC-Cmd/Sup | 608.00 |

Personnel Transferred (.2)

| | |
|---|---|
| DISC-IM | 0.00 |
| DISC-Buyer | 50.00 |
| DISC-Cmd/Sup | 289.42 |
| DGSC-IM | 0.00 |
| DGSC-Buyer | 0.00 |
| DGSC-Cmd/Sup | 0.00 |
| DCSC-IM | 42.00 |
| DCSC-Buyer | 0.00 |
| DCSC-Cmd/Sup | 64.58 |

ADP Units Added

| | |
|---|---|
| DISC | 6.09 |
| DGSC | 0.00 |
| DCSC | 3.77 |

Total Cost

63,636,463.88

Iterations

45

TABLE 11

DESC Eliminated-Integers Required

**Items Gained**

| | |
|---|---|
| DISC | 500000.00 |
| DGSC | 0.00 |
| DCSC | 321499.00 |

**Space Added**

| | |
|---|---|
| DISC | 2.00 |
| DGSC | 0.0 |
| DCSC | 2.00 |

**Personnel Hired**

| | |
|---|---|
| DISC-IM | 126.11 |
| DISC-Buyer | 101.76 |
| DISC-Cmd/Sup | 803.00 |
| DGSC-IM | 0.00 |
| DGSC-Buyer | 0.00 |
| DGSC-Cmd/Sup | 0.00 |
| DCSC-IM | 38.70 |
| DCSC-Buyer | 97.11 |
| DCSC-Cmd/Sup | 608.00 |

**Personnel Transferred (.2)**

| | |
|---|---|
| DISC-IM | 0.00 |
| DISC-Buyer | 50.00 |
| DISC-Cmd/Sup | 273.30 |
| DGSC-IM | 0.00 |
| DGSC-Buyer | 0.00 |
| DGSC-Cmd/Sup | 0.00 |
| DCSC-IM | 42.00 |
| DCSC-Buyer | 0.00 |
| DCSC-Cmd/Sup | 80.70 |

**ADP Units Added**

| | |
|---|---|
| DISC | 6.00 |
| DGSC | 0.00 |
| DCSC | 4.00 |

**Total Cost**

70,999,675.87

**Iterations**

3808

TABLE 12

DESC Eliminated Cost Percentages
Percent of Total Cost*

| Costs | .2 Transfers Optional | .2 Transfers Required | ADP and Space Required Integers |
|---|---|---|---|
| ADP | 2 | 2 | 2 |
| Space | 57 | 49 | 54 |
| Hires | 35 | 28 | 24 |
| Transfers | 5 | 21 | 19 |

* Percentages do not always add up to 100 because of rounding

TABLE 13

DESC Eliminated-Sensitive Coefficients

| Variable | Coefficient | Restricting Bound Upper | Restricting Bound Lower |
|---|---|---|---|
| Buyer hires-DCSC | 33425. | 36247. | None |
| Cmd/Sup hires-DISC | 1793. | 1793. | None |
| Cmd/Sup hires-DGSC | 1793. | 1793. | None |
| Cmd/Sup hires-DCSC | 1793. | None | 1793. |
| ADP added-DISC | 125000. | 125000. | 125000. |
| ADP added-DCSC | 125000. | 125000. | None |
| Space added-DISC | 9600000. | None | 9383100. |
| Space added-DGSC | 9600000. | None | 9383100. |
| Space added-DCSC | 9600000. | 9816900. | None |
| Buyer transfers-DISC | 30000. | 32822. | 27091. |
| Buyer transfers-DGSC | 30000. | 32909. | 27178. |
| Cmd/Sup transfers-DISC | 30000. | 32162. | 30000. |
| Cmd/Sup transfers-DCSC | 30000. | 30000. | 27838. |

TABLE 14

DESC Eliminated-Sensitive Constants

| Constraint | Right-Hand-Side Constant | Restricting Bound Upper | Lower |
|---|---|---|---|
| Items managed | 821500. | 823930. | None |
| ADP required-DGSC | 0. | 0. | None |
| Space required-DGSC | 0. | 0. | None |
| Cmd/Sup required-system | 1765. | None | 1759.8 |
| IM hire-DISC | 128. | 135.57 | None |
| Cmd/Sup hire-DISC | 803. | None | 738.42 |
| IM/Buyer ratio-DGSC | 0. | 0. | None |
| Buyer/(Cmd/Sup) ratio-DCSC | 0. | 0. | None |
| IM/Item ratio-DCSC | 0. | .61 | None |

the number of command/support hires at DISC, the number of command/support hires at DGSC, the number of ADP units added at DISC, the number of ADP units added at DCSC, or the number of command/support transfers at DCSC. Since the costs are so critical, the user has to know the accuracy of his cost figures. The most critical right-hand-side constant was the number of items managed by DESC. This figure would probably be correct as of the date of the source, since the Headquarters closely monitors the count of items managed.

Table 15 displays the results from increasing the cost of transferring command/support personnel to DCSC by one dollar. Table 16 shows the results from increasing the cost of hiring command/support personnel at DISC by one dollar. The most interesting fact about these results is that even though the solution changed, as expected from the sensitivity analysis, the change in the total cost was negligible. As in the DCSC eliminated case, this fact means that the solutions are reasonable alternatives. Factors external to the model would be quite significant. DGSC, because it is comparatively so expensive, is excluded from the solutions. This information would be an extremely valuable input to a trade-off analysis done for DLA decision makers.

DGSC Eliminated. If DGSC is the site eliminated, the results of the three runs are displayed in Tables 17, 18, and 19; the cost percentages are in Table 20; and the sensitivity results are in Tables 21 and 22. When transfers are optional, all remaining locations gain items to manage. DISC gains

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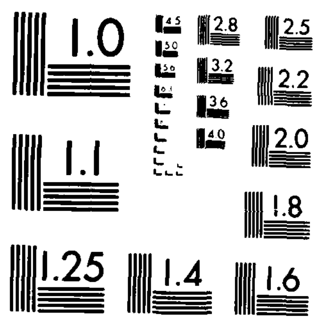


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TABLE 15

DESC Eliminated-DCSC Transfers ($30001)

**Items Gained**

| | |
|---|---|
| DISC | 507527.63 |
| DGSC | 0.00 |
| DCSC | 313971.37 |

**Space Added**

| | |
|---|---|
| DISC | 2.00 |
| DGSC | 0.00 |
| DCSC | 1.23 |

**Personnel Hired**

| | |
|---|---|
| DISC-IM | 128.00 |
| DISC-Buyer | 104.03 |
| DISC-Cmd/Sup | 738.42 |
| DGSC-IM | 0.00 |
| DGSC-Buyer | 0.00 |
| DGSC-Cmd/Sup | 0.00 |
| DCSC-IM | 36.81 |
| DCSC-Buyer | 94.83 |
| DCSC-Cmd/Sup | 672.58 |

**Personnel Transferred (.2)**

| | |
|---|---|
| DISC-IM | 0.00 |
| DISC-Buyer | 50.00 |
| DISC-Cmd/Sup | 354.00 |
| DGSC-IM | 0.00 |
| DGSC-Buyer | 0.00 |
| DGSC-Cmd/Sup | 0.00 |
| DCSC-IM | 42.00 |
| DCSC-Buyer | 0.00 |
| DCSC-Cmd/Sup | 0.00 |

**ADP Units Added**

| | |
|---|---|
| DISC | 6.09 |
| DGSC | 0.00 |
| DCSC | 3.77 |

**Total Cost**

63,636,463.88

**Iterations**

45

TABLE 16

DESC Eliminated-DISC Hires ($1794)

| Items Gained | |
|---|---|
| DISC | 507527.63 |
| DGSC | 0.00 |
| DCSC | 313971.37 |

| Space Added | |
|---|---|
| DISC | 2.00 |
| DGSC | 0.00 |
| DCSC | 1.23 |

| Personnel Hired | |
|---|---|
| DISC-IM | 128.00 |
| DISC-Buyer | 104.03 |
| DISC-Cmd/Sup | 738.42 |
| DGSC-IM | 0.00 |
| DGSC-Buyer | 0.00 |
| DGSC-Cmd/Sup | 0.00 |
| DCSC-IM | 36.81 |
| DCSC-Buyer | 94.83 |
| DCSC-Cmd/Sup | 672.58 |

| Personnel Transferred (.2) | |
|---|---|
| DISC-IM | 0.00 |
| DISC-Buyer | 50.00 |
| DISC-Cmd/Sup | 354.00 |
| DGSC-IM | 0.00 |
| DGSC-Buyer | 0.00 |
| DGSC-Cmd/Sup | 0.00 |
| DCSC-IM | 42.00 |
| DCSC-Buyer | 0.00 |
| DCSC-Cmd/Sup | 0.00 |

| ADP Units Added | |
|---|---|
| DISC | 6.09 |
| DGSC | 0.00 |
| DCSC | 3.77 |

Total Cost

63,637,202.30

Iterations

45

TABLE 17

DGSC Eliminated-Transfers Optional

**Items Gained**

| | |
|---|---|
| DESC | 32530.38 |
| DISC | 125700.38 |
| DCSC | 88546.23 |

**Space Added**

| | |
|---|---|
| DESC | .38 |
| DISC | 1.48 |
| DCSC | 1.05 |

**Personnel Hired**

| | |
|---|---|
| DESC-IM | 16.07 |
| DESC-Buyer | 0.00 |
| DESC-Cmd/Sup | 207.81 |
| DISC-IM | 62.10 |
| DISC-Buyer | 128.00 |
| DISC-Cmd/Sup | 803.00 |
| DCSC-IM | 19.02 |
| DCSC-Buyer | 105.30 |
| DCSC-Cmd/Sup | 569.19 |

**Personnel Transferred**

| | |
|---|---|
| DESC-IM | 0.00 |
| DESC-Buyer | 38.45 |
| DESC-Cmd/Sup | 0.00 |
| DISC-IM | 0.00 |
| DISC-Buyer | 20.56 |
| DISC-Cmd/Sup | 0.00 |
| DCSC-IM | 25.00 |
| DCSC-Buyer | 0.00 |
| DCSC-Cmd/Sup | 0.00 |

**ADP Units Added**

| | |
|---|---|
| DESC | 1.33 |
| DISC | 5.15 |
| DCSC | 3.63 |

**Total Cost**

47,721,246.62

**Iterations**

34

TABLE 18

DGSC Eliminated-Transfers Required

| Items Gained | | Space Added | |
|---|---|---|---|
| DESC | 0.00 | DESC | 0.00 |
| DISC | 157677.00 | DISC | 1.86 |
| DCSC | 89100.00 | DCSC | 1.05 |

| Personnel Hired | | Personnel Transferred (.2) | |
|---|---|---|---|
| DESC-IM | 0.00 | DESC-IM | 0.00 |
| DESC-Buyer | 0.00 | DESC-Buyer | 0.00 |
| DESC-Cmd/Sup | 0.00 | DESC-Cmd/Sup | 0.00 |
| DISC-IM | 78.17 | DISC-IM | 0.00 |
| DISC-Buyer | 128.00 | DISC-Buyer | 59.00 |
| DISC-Cmd/Sup | 803.00 | DISC-Cmd/Sup | 207.81 |
| DCSC-IM | 19.02 | DCSC-IM | 25.00 |
| DCSC-Buyer | 105.30 | DCSC-Buyer | 0.00 |
| DCSC-Cmd/Sup | 460.00 | DCSC-Cmd/Sup | 109.19 |

| ADP Units Added | |
|---|---|
| DESC | 0.00 |
| DISC | 6.46 |
| DCSC | 3.56 |

Total Cost

56,573,660.99

Iterations

46

TABLE 19

DGSC Eliminated-Integers Required

| Items Gained | | Space Added | |
|---|---|---|---|
| DESC | 0.00 | DESC | 0.00 |
| DISC | 84479.99 | DISC | 1.00 |
| DCSC | 162297.01 | DCSC | 2.00 |

| Personnel Hired | | Personnel Transferred (.2) | |
|---|---|---|---|
| DESC-IM | 0.00 | DESC-IM | 0.00 |
| DESC-Buyer | 0.00 | DESC-Buyer | 0.00 |
| DESC-Cmd/Sup | 0.00 | DESC-Cmd/Sup | 0.00 |
| DISC-IM | 42.01 | DISC-IM | 0.00 |
| DISC-Buyer | 41.49 | DISC-Buyer | 59.00 |
| DISC-Cmd/Sup | 543.21 | DISC-Cmd/Sup | 0.00 |
| DCSC-IM | 55.17 | DCSC-IM | 25.00 |
| DCSC-Buyer | 191.81 | DCSC-Buyer | 0.00 |
| DCSC-Cmd/Sup | 719.79 | DCSC-Cmd/Sup | 317.00 |

| ADP Units Added | |
|---|---|
| DESC | 0.00 |
| DISC | 4.00 |
| DCSC | 7.00 |

Total Cost

58,107,115.66

Iterations

998

TABLE 20

DGSC Eliminated Cost Percentages
Percent of Total Cost*

| Costs | .2 Transfers Optional | .2 Transfers Required | ADP and Space Required Integers |
|---|---|---|---|
| ADP | 3 | 2 | 2 |
| Space | 59 | 49 | 50 |
| Hires | 34 | 27 | 27 |
| Transfers | 5 | 21 | 21 |

* Percentages do not always add up to 100 because of rounding

TABLE 21

DGSC Eliminated-Sensitive Coefficients

| Variable | Coefficient | Restricting Bound Upper | Restricting Bound Lower |
|---|---|---|---|
| Cmd/Sup hires-DISC | 1793. | 1793. | None |
| Cmd/Sup hires-DCSC | 1793. | None | 1793. |
| ADP added-DESC | 125000. | 125000. | None |
| ADP added-DISC | 125000. | None | 125000. |
| ADP added-DCSC | 125000. | 125000. | None |
| Space added-DESC | 9600000. | None | 9366800. |
| Space added-DISC | 9600000. | 9833200. | 9035300. |
| Space added-DCSC | 9600000. | 10165000. | 8965800. |
| Buyer transfers-DESC | 30000. | None | 27680. |
| Buyer transfers-DISC | 30000. | 32320. | None |
| Cmd/Sup transfers-DISC | 30000. | 30429. | 30000. |
| Cmd/Sup transfers-DCSC | 30000. | 30000. | 29571. |

TABLE 22

DGSC Eliminated-Sensitive Constants

| Constraint | Right-Hand-Side Constant | Restricting Bound Upper | Restricting Bound Lower |
|---|---|---|---|
| Items managed | 246780. | 247330. | None |
| ADP required-DESC | 0. | 0. | None |
| Space required-DESC | 0. | 0. | None |
| Cmd/Sup required-system | 1580. | None | 1578.4 |
| IM/Item ratio-DESC | 0. | 0. | None |
| IM/Item ratio-DCSC | 0. | .27 | None |

the most items followed by DCSC and DESC. DISC hits the ceiling on the hiring of buyer personnel and the hiring of command/support personnel. These results could be expected because of the relatively low cost of complementing the available resources at DISC. When transfers are required DESC drops out of the solution. It is more expensive to build a facility at DESC to cover hires and transfers, than it is to add the transfers onto the workforces at DISC and DCSC. In the integer solution process, not only does DESC remain out of the system, but also DCSC gains the most items. This switch occurs because the cost of adding an entire space unit to DCSC and filling it is less than the similar cost at DISC. The integer requirement forces this change. The cost percentages do not reveal anything unusual. The sensitivity analysis points out the sensitivity of the model to the input parameters. The basis will change if a one-dollar increase happens in the cost of hiring command/support personnel at DISC, the cost of adding ADP units at DESC, the cost of adding ADP units at DCSC, and the cost of transferring command/support personnel to DCSC. This severe sensitivity would affect any use of the model in the plans process. The most significant right-hand-side constant is the one for items managed at DGSC. This figure could definitely be obtained with some degree of confidence during data compilation, even though the number of items managed changes frequently.

Table 23 lists the results from increasing the cost of transferring command/support personnel to DCSC by one dollar. Table 24 displays the results from increasing the cost of hiring command/support personnel at DISC by one dollar. As expected, the solution set changes, but in each case the change in total cost is insignificant. As in the first two cases, this lack of change means that the solutions are reasonable alternatives. In both runs DESC is excluded from the solution. These results point out that elements not included in the model would play major roles in the decision making process.

DISC Eliminated. When DISC is eliminated from the system, the results of the three runs are shown in Tables 25, 26, and 27; the cost percentages are in Table 28; the sensitivity analysis results are in Tables 29 and 30. In the cases when transfers are optional and when transfers are required, DCSC gains the most items followed by DESC and DGSC. In fact, the number of items gained by each remaining ICP is the same for the two scenarios. This result is keyed by the fact that DESC and DCSC reach the hiring ceiling on IM personnel i both situations. They reach the ceiling because it is much more expensive to hire IM personnel at DGSC. The only difference happens when 20 percent transfers are required, because then DESC acquires all the transfers, since it has the lowest costs among the remaining sites. A major change occurs when the integer requirements are set. DESC gains the most items followed by DCSC and DGSC. The

TABLE 23

DGSC Eliminated-DCSC Transfers ($30001)

Items Gained

| | |
|---|---|
| DESC | 0.00 |
| DISC | 157677.00 |
| DCSC | 89100.00 |

Space Added

| | |
|---|---|
| DESC | 0.00 |
| DISC | 1.86 |
| DCSC | 1.05 |

Personnel Hired

| | |
|---|---|
| DESC-IM | 0.00 |
| DESC-Buyer | 0.00 |
| DESC-Cmd/Sup | 0.00 |
| DISC-IM | 78.17 |
| DISC-Buyer | 128.00 |
| DISC-Cmd/Sup | 693.81 |
| DCSC-IM | 19.02 |
| DCSC-Buyer | 105.30 |
| DCSC-Cmd/Sup | 569.19 |

Personnel Transferred (.2)

| | |
|---|---|
| DESC-IM | 0.00 |
| DESC-Buyer | 0.00 |
| DESC-Cmd/Sup | 0.00 |
| DISC-IM | 0.00 |
| DISC-Buyer | 59.00 |
| DISC-Cmd/Sup | 317.00 |
| DCSC-IM | 25.00 |
| DCSC-Buyer | 0.00 |
| DCSC-Cmd/Sup | 0.00 |

ADP Units Added

| | |
|---|---|
| DESC | 0.00 |
| DISC | 6.46 |
| DCSC | 3.65 |

Total Cost

56,573,660.99

Iterations

45

TABLE 24

DGSC Eliminated-DISC Hires ($1794)

| Items Gained | | Space Added | |
|---|---|---|---|
| DESC | 0.00 | DESC | 0.00 |
| DISC | 157677.00 | DISC | 1.86 |
| DCSC | 89100.00 | DCSC | 1.05 |

| Personnel Hired | | Personnel Transferred (.2) | |
|---|---|---|---|
| DESC-IM | 0.00 | DESC-IM | 0.00 |
| DESC-Buyer | 0.00 | DESC-Buyer | 0.00 |
| DESC-Cmd/Sup | 0.00 | DESC-Cmd/Sup | 0.00 |
| DISC-IM | 78.17 | DISC-IM | 0.00 |
| DISC-Buyer | 128.00 | DISC-Buyer | 59.00 |
| DISC-Cmd/Sup | 693.81 | DISC-Cmd/Sup | 317.00 |
| DCSC-IM | 19.02 | DCSC-IM | 25.00 |
| DCSC-Buyer | 105.30 | DCSC-Buyer | 0.00 |
| DCSC-Cmd/Sup | 569.19 | DCSC-Cmd/Sup | 0.00 |

| ADP Units Added | |
|---|---|
| DESC | 0.00 |
| DISC | 6.46 |
| DCSC | 3.56 |

Total Cost

56,574,354.80

Iterations

45

TABLE 25

DISC Eliminated-Transfers Optional

**Items Gained**

| | |
|---|---|
| DESC | 292935.79 |
| DGSC | 22535.21 |
| DCSC | 400000.00 |

**Space Added**

| | |
|---|---|
| DESC | 1.26 |
| DGSC | .10 |
| DCSC | 1.72 |

**Personnel Hired**

| | |
|---|---|
| DESC-IM | 104.00 |
| DESC-Buyer | 53.00 |
| DESC-Cmd/Sup | 658.23 |
| DGSC-IM | 8.00 |
| DGSC-Buyer | 8.00 |
| DGSC-Cmd/Sup | 50.63 |
| DCSC-IM | 91.00 |
| DCSC-Buyer | 142.00 |
| DCSC-Cmd/Sup | 898.73 |

**Personnel Transferred**

| | |
|---|---|
| DESC-IM | 0.00 |
| DESC-Buyer | 51.00 |
| DESC-Cmd/Sup | 0.00 |
| DGSC-IM | 0.00 |
| DGSC-Buyer | 0.00 |
| DGSC-Cmd/Sup | 0.00 |
| DCSC-IM | 51.00 |
| DCSC-Buyer | 0.00 |
| DCSC-Cmd/Sup | 0.00 |

**ADP Units Added**

| | |
|---|---|
| DESC | 4.10 |
| DGSC | .32 |
| DCSC | 5.60 |

**Total Cost**

56,726,976.09

**Iterations**

33

TABLE 26

DISC Eliminated-Transfers Required

| Items Gained | | Space Added | |
|---|---|---|---|
| DESC | 292935.79 | DESC | 1.26 |
| DGSC | 22535.21 | DGSC | .10 |
| DCSC | 400000.00 | DCSC | 1.72 |

| Personnel Hired | | Personnel Transferred (.2) | |
|---|---|---|---|
| DESC-IM | 104.00 | DESC-IM | 0.00 |
| DESC-Buyer | 53.00 | DESC-Buyer | 51.00 |
| DESC-Cmd/Sup | 336.23 | DESC-Cmd/Sup | 322.00 |
| DGSC-IM | 8.00 | DGSC-IM | 0.00 |
| DGSC-Buyer | 8.00 | DGSC-Buyer | 0.00 |
| DGSC-Cmd/Sup | 50.63 | DGSC-Cmd/Sup | 0.00 |
| DCSC-IM | 91.00 | DCSC-IM | 51.00 |
| DCSC-Buyer | 142.00 | DCSC-Buyer | 0.00 |
| DCSC-Cmd/Sup | 898.73 | DCSC-Cmd/Sup | 0.00 |

| ADP Units Added | | Total Cost |
|---|---|---|
| DESC | 4.10 | 65,809,630.09 |
| DGSC | .32 | Iterations |
| DCSC | 5.60 | 38 |

TABLE 27

DISC Eliminated-Integers Required

| Items Gained | |
|---|---|
| DESC | 285714.29 |
| DGSC | 197848.55 |
| DCSC | 231908.27 |

| Space Added | |
|---|---|
| DESC | 2.00 |
| DGSC | 1.00 |
| DCSC | 1.00 |

| Personnel Hired | |
|---|---|
| DESC-IM | 101.44 |
| DESC-Buyer | 50.44 |
| DESC-Cmd/Sup | 320.00 |
| DGSC-IM | 19.24 |
| DGSC-Buyer | 70.24 |
| DGSC-Cmd/Sup | 444.53 |
| DCSC-IM | 82.33 |
| DCSC-Buyer | 82.33 |
| DCSC-Cmd/Sup | 521.06 |

| Personnel Transferred (.2) | |
|---|---|
| DESC-IM | 0.00 |
| DESC-Buyer | 51.00 |
| DESC-Cmd/Sup | 322.00 |
| DGSC-IM | 51.00 |
| DGSC-Buyer | 0.00 |
| DGSC-Cmd/Sup | 0.00 |
| DCSC-IM | 0.00 |
| DCSC-Buyer | 0.00 |
| DCSC-Cmd/Sup | 0.00 |

| ADP Units Added | |
|---|---|
| DESC | 4.00 |
| DGSC | 3.00 |
| DCSC | 4.00 |

Total Cost

75,251,252.37

Iterations

1356

TABLE 28

DISC Eliminated Cost Percentages
Percent of Total Cost*

| Costs | .2 Transfers Optional | .2 Transfers Required | ADP and Space Required Integers |
|---|---|---|---|
| ADP | 2 | 2 | 2 |
| Space | 52 | 45 | 51 |
| Hires | 40 | 34 | 30 |
| Transfers | 5 | 19 | 17 |

* Percentages do not always add up to 100 because of rounding

TABLE 29

DISC Eliminated-Sensitive Coefficients

| Variable | Coefficient | Restricting Bound Upper | Restricting Bound Lower |
|---|---|---|---|
| Cmd/Sup hires-DESC | 1793. | None | 1793. |
| Cmd/Sup hires-DGSC | 1793. | 1793. | None |
| Cmd/Sup hires-DCSC | 1793. | 1793. | None |
| ADP added-DESC | 125000. | None | 125000. |
| ADP added-DGSC | 125000. | 125000. | None |
| ADP added-DCSC | 125000. | 125000. | None |
| Space added-DGSC | 9600000. | None | 9128200. |
| Space added-DCSC | 9600000. | 10072000. | None |
| Cmd/Sup transfers-DESC | 30000. | 30000. | None |

TABLE 30

DISC Eliminated-Sensitive Constants

| Constraint | Right-Hand-Side Constant | Restricting Bound Upper | Lower |
|---|---|---|---|
| Items managed | 715470. | 715490. | None |
| ADP required-DGSC | 0. | .32 | None |
| IM required-system | 254. | None | 254. |
| IM hire-DESC | 104. | 112. | None |
| IM hire-DCSC | 91. | 99. | None |
| IM/Buyer ratio-DESC | 0. | 0. | None |
| IM/Buyer ratio-DGSC | 0. | 0. | None |
| IM/Buyer ratio-DCSC | 0. | 0. | None |
| Buyer/(Cmd/Sup) ratio-DESC | 0. | .41 | None |
| Buyer/(Cmd/Sup) ratio-DGSC | 0. | .41 | None |
| Buyer/(Cmd/Sup) ratio-DCSC | 0. | .41 | None |
| IM/Item ratio-DGSC | 0. | .008 | None |
| IM/Item ratio-DCSC | 0. | .008 | None |

cause is the integer requirement on space. Since a facility must be built at DGSC, it is used to the fullest extent considering the cost. DESC adds two space units, since it is less expensive to hire people there than it is at DCSC. The cost percentages are the values expected given the input parameters. Ranging revealed that the model was quite sensitive. The basis will change if a one-dollar increase occurs in the cost of command/support hires at DGSC, command/support hires at DCSC, ADP units added at DGSC, ADP units added at DCSC, and command/support transfers at DESC. The right-hand-side constants associated with the following three constraints are sensitive: number of items managed by DISC, the IM hiring ceiling at DESC, and the IM hiring ceiling at DCSC. This extreme sensitivity would affect any application of the model in a planning situation.

Table 31 shows what happens if the cost of transferring command/support personnel to DESC is increased by one dollar. Table 32 portrays the results if the cost of hiring command/support personnel at DCSC is raised by one dollar. As predicted from sensitivity analysis the basic solution changes, but the total cost essentially remains the same. As in the other three cases, the similar total cost means that the solutions are alternatives. These results once again demonstrate the fact that elements not included in the model would be extremely significant in the decision making process.

## Model Verification and Validation

The results from the elimination of each ICP verify that the model does what it was intended to do. The model reallocates resources over a realigned distribution system. Personnel are hired, personnel are transferred, ADP disks are added, and space units are added. All of these events occur as expected given the structure of the model. The total costs agree with the intuitive concept of the problem. The problem with optional transfers of personnel is the least expensive, then follows the problem with required transfers of personnel, and finally, the problem with integer requirements and transfers of personnel required.

Model validation is a different issue. The results from the model can not be proven correct or incorrect until an actual catastrophe occurs. It is hoped that such a disaster will not happen, but if it should, then this model could yield reasonable macro-level results for planning purposes. Responsible use of the model would have to cite the importance of accurate costs and the significance of the initial assumptions. Considering these two factors, if the costs are obtained with a fairly high degree of accuracy and if the assumptions are fully comprehended by the decision makers, then the model can definitely be used for emergency planning purposes.

TABLE 31

DISC Eliminated-DESC Transfers ($30001)

| Items Gained | | Space Added | |
|---|---|---|---|
| DESC | 292935.79 | DESC | 1.26 |
| DGSC | 22535.21 | DGSC | .10 |
| DCSC | 400000.00 | DCSC | 1.72 |

| Personnel Hired | | Personnel Transferred (.2) | |
|---|---|---|---|
| DESC-IM | 104.00 | DESC-IM | 0.00 |
| DESC-Buyer | 53.00 | DESC-Buyer | 51.00 |
| DESC-Cmd/Sup | 658.23 | DESC-Cmd/Sup | 0.00 |
| DGSC-IM | 8.00 | DGSC-IM | 0.00 |
| DGSC-Buyer | 8.00 | DGSC-Buyer | 0.00 |
| DGSC-Cmd/Sup | 0.00 | DGSC-Cmd/Sup | 50.63 |
| DCSC-IM | 91.00 | DCSC-IM | 51.00 |
| DCSC-Buyer | 142.00 | DCSC-Buyer | 0.00 |
| DCSC-Cmd/Sup | 627.37 | DCSC-Cmd/Sup | 271.37 |

| ADP Units Added | |
|---|---|
| DESC | 4.10 |
| DGSC | .32 |
| DCSC | 5.60 |

Total Cost

65,809,630.09

Iterations

40

TABLE 32

DISC Eliminated-DCSC Hires ($1794)

| Items Gained | |
|---|---|
| DESC | 292935.79 |
| DGSC | 22535.21 |
| DCSC | 400000.00 |

| Space Added | |
|---|---|
| DESC | 1.26 |
| DGSC | .10 |
| DCSC | 1.72 |

| Personnel Hired | |
|---|---|
| DESC-IM | 104.00 |
| DESC-Buyer | 53.00 |
| DESC-Cmd/Sup | 658.23 |
| DGSC-IM | 8.00 |
| DGSC-Buyer | 8.00 |
| DGSC-Cmd/Sup | 50.63 |
| DCSC-IM | 91.00 |
| DCSC-Buyer | 142.00 |
| DCSC-Cmd/Sup | 576.73 |

| Personnel Transferred (.2) | |
|---|---|
| DESC-IM | 0.00 |
| DESC-Buyer | 51.00 |
| DESC-Cmd/Sup | 0.00 |
| DGSC-IM | 0.00 |
| DGSC-Buyer | 0.00 |
| DGSC-Cmd/Sup | 0.00 |
| DCSC-IM | 51.00 |
| DCSC-Buyer | 0.00 |
| DCSC-Cmd/Sup | 322.00 |

| ADP Units Added | |
|---|---|
| DESC | 4.10 |
| DGSC | .32 |
| DCSC | 5.60 |

Total Cost

65,810,206.82

Iterations

39

# VI. Depot System Analysis

Using the depot model, an analysis was performed of the emergency situation that would occur if the Defense Depot at Memphis were destroyed in a catastrophe. This chapter will cover the application of the model, the programming of the model, and the results obtained from the model.

## Model Application

After formulating the model and compiling the data elements, as cited in Chapters III and IV, the next step was to select a scenario to show the application of the model. The depot at Memphis was chosen for several reasons. First, the central location of Memphis in the system would mean that the model would have to show that it could allocate a major workload to all other depots in order to get the mission accomplished. Secondly, since only the hardware commodities are being considered, Memphis was considered a significant player because only the depot at Tracy shipped more weight than Memphis. The loss of Memphis would require that the system redistribute a major part of its workload. Thirdly, Memphis stocks only three of the four hardware commodities. The loss of this depot would demonstrate that the model could be used in a situation in which not all depots store all commodities. Fourthly, Memphis employs the largest number of personnel in the system, therefore the loss of Memphis would require not only reallocation of workload, but

also a significant reallocation of the personnel requirement across all the remaining depots.

All of the data compiled on the Memphis depot then had to be put into the model for use by the Northwestern University Multi-Purpose Optimization System (MPOS) linear programming package. A major decision relating to these data was the way in which the commodity restrictions and customer restrictions would be programmed. MPOS is a very explicit package. Because of this structure, it could take an exceptionally long time to program the model. The final decision was that the best way to handle the commodity restrictions was to program the restrictions as constraints when the commodity is stocked at a depot. If a commodity is not stocked by a depot, then the cost coefficients in the objective function for that commodity and that depot were made exceptionally large by applying the Big M method. These large coefficients prevent shipments from ever being made from those depots. The customer restrictions were handled in a similar manner. If a depot is not allowed to ship a specific commodity to a customer, then the cost coefficient in the object tive function is made quite large. According to the Big M method, this high coefficient insures that certain commodities are not shipped from certain depots to certain customers. If such a shipment were made, it would indicate an error in the program. The commodity restrictions would not vary depending on which depot was destroyed. The customer restrictions would change depending on which depot was

eliminated. As long as a given commodity is stocked, remaining depots would be allowed to ship to all areas served by the destroyed depot. This provision is made because in each scenario the demands of all customers must be satisfied. If a commodity has to be shipped from the West Coast to the East Coast to satisfy a demand, then it will be done, but the shipment will definitely cost more. Such shipments would not occur often, but they would be used to satisfy the customers. Allowing remaining depots to serve all customers of the destroyed site also allows a customer workload to be split among two or more depots in order to minimize the cost of the realigned system.

Another issue in building the model involved the number of customers who would be used. The customers are categorized by state and geographical part of the world. In the transportation reports, this breakdown yields 57 customers - 48 states, the District of Columbia, and eight overseas areas. If the problem used all 57 customers, then MPOS could not be used because of the number of variables involved. In spite of this input limitation, it was desirable to use MPOS because of its availability, its easily understood input format, and its numerous output options. The best way to lower the number of customers and retain the validity of the model was to aggregate the customers in contiguous areas. Using this concept, eleven customers were created. The 48 states and the District of Columbia were reduced to nine customers. The eight overseas customers were made into an

Atlantic Theater and a Pacific Theater. The final customer composition is shown in Table 33.

## Model Implementation

The model was then run using the MPOS form of the model as shown in Appendix D. This base line run of the model worked only for the MPOS DUAL algorithm. The check was not satisfactory for either REGULAR, REVISED, or PREVISED. The personnel at the Vogelback Computing Center at Northwestern University could not explain why the check was so poor. They did verify that the DUAL solution was theoretically correct. The algorithm recognizes the fact that the user reads in the primal problem. With this initial run it was apparent that several other runs could be made examining the sensitivity of certain parameters and the significance of certain policies.

## Results From Model

Original Policy Results. Tables 34 and 35 display the solution using input parameters developed from the original policy for system realignment. Space units can be purchased or leased in the proximity of each remaining depot. Additional ADP disk drives must be purchased. Twenty percent of the Memphis personnel must be transferred to other locations. All five remaining depots are allowed to ship to Memphis customers. The gaining depots use the Memphis utilization factors on the assumption that depot ADP, personnel, and space will be used just as efficiently at the gaining depot

TABLE 33

Depot Customers

| | |
|---|---|
| Customer 1: | Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont |
| Customer 2: | Delaware, District of Columbua, Maryland, New Jersey, New York, Pennsylvania, Virginia, West Virginia |
| Customer 3: | Florida, Georgia, North Carolina, South Carolina |
| Customer 4: | Illinois, Indiana, Kentucky, Michigan, Ohio, Wisconsin |
| Customer 5: | Alabama, Arkansas, Louisiana, Mississippi, Missouri, Tennessee |
| Customer 6: | Iowa, Minnesota, Nebraska, North Dakota, South Dakota |
| Customer 7: | Colorado, Kansas, New Mexico, Oklahoma, Texas |
| Customer 8: | Idaho, Montana, Oregon, Washington, Wyoming |
| Customer 9: | Arizona, California, Nevada, Utah |
| Customer 10: | European Theater |
| Customer 11: | Pacific Theater |

TABLE 34

System Realignment-Original Policy Results

<u>Mechanicsburg</u>

| | |
|---|---|
| Space units purchased | 0.00 |
| Space units leased | 3.31 |
| ADP units added | .96 |
| Personnel transferred | 0.00 |
| Personnel hired | 442.68 |

<u>Ogden</u>

| | |
|---|---|
| Space units purchased | 0.00 |
| Space units leased | 0.00 |
| ADP units added | 1.18 |
| Personnel transferred | 458.00 |
| Personnel hired | 85.49 |

<u>Richmond (DGSC)</u>

| | |
|---|---|
| Space units purchased | 0.00 |
| Space units leased | 8.19 |
| ADP units added | 2.50 |
| Personnel transferred | 0.00 |
| Personnel hired | 1156.55 |

<u>Tracy</u>

| | |
|---|---|
| Space units purchased | 0.00 |
| Space units leased | .13 |
| ADP units added | .15 |
| Personnel transferred | 0.00 |
| Personnel hired | 71.25 |

<u>Columbus (DCSC)</u>

| | |
|---|---|
| Space units purchased | 0.00 |
| Space units leased | .48 |
| ADP units added | .16 |
| Personnel transferred | 0.00 |
| Personnel hired | 73.47 |

<u>Total Cost</u>

21,844,575.73

Iterations

120

TABLE 35

Customer Assignment-Original Policy Results

| Depot | Construction | Industrial | General |
|---|---|---|---|
| | Commodity | | |
| DDMP | 1,2,10 | 1,2,3,5,10 | 1,10 |
| DGSC | N/A | N/A | 1,2,3,4,7 |
| DCSC | 3,4 | 4 | N/A |
| DDOU | 5,6,7,8,9 | 6,7,8,9 | 6,7,8,9 |
| DDTC | 11 | 11 | 11 |

Note: To achieve minimum cost, shipment of General commodity to Customer 7 is split between two depots.

as they were at Memphis. This assumption is reasonable, because the ADP equipment will be similar, a core of trained personnel will be available at each location, and sufficient space will be procured in the vicinity of the gaining depots to store the materiel. The primary intent of these parameters is to insure that the demands of the customers are satisfied.

The most significant factor in the realignment of resources is the requirement to satisfy customer demand within the bounds of both the commodity and customer restrictions. The next most important factor is the cost of space units at each remaining depot. Given the relatively low annual cost of leasing warehouse space in the Richmond area and the customers that DGSC is allowed to serve, DGSC gains responsibility for distribution of the most materiel. No personnel are transferred to DGSC; over one thousand personnel are hired. The major disadvantage to this solution is that DGSC hires almost as many personnel as it normally employs. This situation would make training extremely difficult. In order to achieve the minimum cost system, all personnel transferred from Memphis are assigned to Ogden. The assignment pattern of customers to depots exhibited no unusual characteristics. Each one of the five depots was allocated a portion of the Memphis workload.

Sensitivity Analysis. Tables 36 and 37 show the sensitivity of the model. The model is exceptionally sensitive to changes in certain cost coefficients and right-hand-side constants. The parameter was included in the tables if a

TABLE 36

Sensitive Coefficients-Original Policy Results

| Variable | Cost Coefficient | Restricting Bound Upper | Restricting Bound Lower |
|---|---|---|---|
| Personnel hires at DGSC | 1793.0 | 1793.0 | None |
| Personnel hires at DDMP | 1793.0 | 1793.0 | None |
| Personnel hires at DCSC | 1793.0 | 1793.0 | None |
| Personnel hires at DDTC | 1793.0 | 1793.0 | 1667.0 |
| Leased space units at DGSC | 240000.0 | 256830.0 | None |
| Leased space units at DDTC | 288000.0 | None | 271170.0 |
| Personnel transfers to DDOU | 30000.0 | 30000.0 | None |

TABLE 37

Sensitive Constants-Original Policy Results

| Constraint | Right-Hand-Side Constant | Restricting Bound Upper | Restricting Bound Lower |
|---|---|---|---|
| Customer 3 demand for General commodity | 15513.0 | 16490.0 | None |
| Customer 5 demand for General commodity | 12781.0 | 13758.0 | None |
| Customer 7 demand for General commodity | 19092.0 | 20068.0 | None |
| ADP required at DDMP | 0. | .96 | None |
| ADP required at DCSC | 0. | .16 | None |
| ADP required at DDTC | 0. | .15 | None |

variance of ten percent or less would change the solution. If some of the costs were increased by one dollar or more, the basic solution would change.

Three of the parameters were modified, to examine the effect on the solution. When the cost of transferring personnel to Ogden was increased to $30,010, the total cost did not change, but the transfers were assigned to Mechanicsburg and DGSC instead of Ogden. When the cost to hire personnel at DGSC was increased to $1803, the total cost increased; all personnel transfers were assigned to DGSC; personnel hired at DGSC decreased by the number of personnel transferred; and personnel hired at Ogden increased, in order to make up for the loss of all the personnel transferred. When the value of the right-hand-side constant for ADP units at DCSC was increased, the total cost decreased, but the decrease was relatively insignificant, because ADP cost has only a minor effect on the solution.

## Modified Policy Results

The policies used in setting up the framework of the problem directly affect model sensitivity. Four changes to the original policies were made to determine the differences from the original solution. When all vacant space is deleted from the system, total cost increases; space units leased increases at all depots except Mechanicsburg; ADP disk drives added increases at DGSC and Tracy; ADP disk drives added

decreases at Ogden; Mechanicsburg gains some personnel transfers; and Ogden loses some personnel transfers.

When personnel hires are limited to 50 percent of the workforce at the gaining location, total cost increases; requirements at DGSC decrease for space units, ADP units, and personnel hires; requirements at both Ogden and Tracy increases for space units, ADP units, and personnel hires; and all personnel transferred are assigned to DGSC instead of Ogden.

When each gaining depot is required to augment its workforce with a workforce consisting of a minimum of ten percent personnel transfers, total cost remains the same; space requirements and ADP requirements are the same; and Ogden is the only depot where the percentage of personnel transferred in the additional workforce is greater than ten percent.

The preferred policy is the one that combines the change in personnel hiring policy (50 percent maximum) with the change in personnel transfer policy (ten percent requirement). The results of this policy modification are in Tables 38 and 39. The cost component breakdown that compares the original policy with this modified policy is in Table 40. In both cases the primary cost component is the cost of transferring personnel. One significant advantage to the modified policy is that personnel hires are limited. This ceiling would definitely improve the training program for new personnel. Another advantage is that each remaining depot

TABLE 38

System Realignment-Modified Policy Results

**Mechanicsburg**

| | |
|---|---|
| Space units purchased | 0.00 |
| Space units leased | 3.31 |
| ADP units added | .96 |
| Personnel transferred | 40.24 |
| Personnel hired | 402.43 |

**Ogden**

| | |
|---|---|
| Space units purchased | 0.00 |
| Space units leased | 1.74 |
| ADP units added | 1.68 |
| Personnel transferred | 70.51 |
| Personnel hired | 705.11 |

**Richmond (DGSC)**

| | |
|---|---|
| Space units purchased | 0.00 |
| Space units leased | 6.40 |
| ADP units added | 1.99 |
| Personnel transferred | 333.46 |
| Personnel hired | 584.00 |

**Tracy**

| | |
|---|---|
| Space units purchased | 0.00 |
| Space units leased | .18 |
| ADP units added | .17 |
| Personnel transferred | 7.11 |
| Personnel hired | 71.11 |

**Columbus (DCSC)**

| | |
|---|---|
| Space units purchased | 0.00 |
| Space units leased | .48 |
| ADP units added | .16 |
| Personnel transferred | 6.68 |
| Personnel hired | 66.79 |

**Total Cost**

21,902,330.86

Iterations

136

TABLE 39

Customer Assignment-Modified Policy Results

| | Commodity | | |
|---|---|---|---|
| Depot | Construction | Industrial | General |
| DDMP | 1,2,10 | 1,2,3,5,10 | 1,10 |
| DGSC | N/A | N/A | 2,3,4,5,7 |
| DCSC | 3,4 | 4 | N/A |
| DDOU | 5,6,7,8 | 6,7,8,9 | 6,7,8,9 |
| DDTC | 9,11 | 11 | 11 |

Note: To achieve minimum cost, shipment of General commodity to Customer 7 is split between two depots.

TABLE 40

System Realignment-Cost Percentages

| Cost Component | Policy | |
|---|---|---|
| | Original | Modified |
| Space units added | 14.8 | 15.2 |
| ADP units added | 2.8 | 2.8 |
| Personnel transferred | 62.9 | 62.7 |
| Personnel hired | 15.0 | 15.0 |
| Transportation | 4.5 | 4.3 |

gains some fully qualified personnel from Memphis. A corollary is that this policy would give the personnel at Memphis a chance to go to any of the other five sites. The total cost does increase, but by less than one percent. The results are certainly reasonable. The benefits of this policy far outweigh the increase in total cost. In order to determine exactly what actions would have to be taken, decision makers would use the model results in conjunction with an evaluation of the factors not included in the model.

## Model Verification and Validation

The depot model successfully realigns resources. Each remaining depot contributes to the accomplishment of the mission. The demands of the customers are satisfied at minimum cost to the government. The customer assignment pattern conforms to the constraints of both the commodity restriction matrix and the customer restriction matrix.

Validation of the model would require an actual catastrophe, but since that is not desirable, a satisfactory substitute is a thorough examination of the results. Given the fundamental assumptions in the model and the accuracy of the input values, the solutions are reasonable. The model provides DLA with a macro-level planning tool for use in the decision making process. The sensitivity of the model would make planners aware of the need for accurate data and the importance of elements excluded from the model.

## VII. Conclusions and Recommendations

This chapter cites the conclusions and recommendations derived from this research. The conclusions follow directly from the results presented in Chapters V and VI. The recommendations examine areas that this thesis reveals are lucrative for further research.

### Conclusions

This thesis proves that both the ICP system and the depot system can be modeled for use in emergency planning. At the macro-level, both the ICP model and the depot model provide insight into what realignment actions would have to occur and the potential magnitude of the actions after a catastrophe. This research definitely sheds light on the problem even though it does not yield a final solution. Certain aspects of the distribution system are quantified for use by DLA planners in developing planning factors. A careful examination of the results will enhance the DLA planning process. The final actions taken by the DLA Commander would be greatly affected by elements excluded from the model. These elements would concern elements such as the number of personnel who would actually be willing to transfer from the area of the destroyed facility, the number of space units available for leasing in the vicinity of remaining centers or depots, the number of fully qualified personnel available for hire in the proximity of the remaining centers

or depots, and the amount of time required to complement the facilities and personnel at the gaining locations. If an additional requirement were small, the Commander would probably dictate that the location absorb the new workload within its existing structure. Additional space requirements for some types of items could be met through the prudent use of tents.

Another strong influence on the realignment actions would be the fact that alternative optimal feasible solutions to the ICP model exist. These solutions occur because some of the costs associated with the different locations are the same. Those equal costs make the model extremely sensitive as shown in Tables 5, 6, 13, 14, 21, 22, 29 and 30, where in effect the upper or lower bound on the factors is the same as the factor value. This is the result of several cost factors being equal for all alternative sites (See recommendation number 5).

One situation that could happen would be the loss of a location that has both a center and a depot. The models could be used in this case because the data bases are different. The ADP, space, and personnel figures were developed separately for each organization. For example, the center personnel data exclude the Directorate of Storage and Transportation; the depot data include only the personnel from that directorate. However, planners must remember that the models do not capture the total interaction that occurs at a joint location. The results from the models would just be

an input to the decision making process. They would not present a complete solution.

In spite of some of the limitations of these two models, the primary achievement of this thesis is that it has produced benchmark research for the further development of DLA planning models.

## Recommendations

The analysis of the results from the two models proved that this research could be expanded in numerous lucrative areas. The accomplishment of further research would definitely improve the ability of DLA planners to prepare for a potential catastrophe.

The following list of recommendations has been developed based on this thesis:

1. Investigate an improved formulation for the utility factors;

2. Automate the data base for both models and have it periodically updated;

3. Determine whether or not digital communications could ever be a limiting factor in either model;

4. Explore the use of personnel on overtime in both models;

5. Make the models less sensitive by obtaining more accurate cost data that would reflect the differences in costs from one geographical area to another;

6. Separate the rates of pay for military personnel, General Schedule personnel, and Wage Grade personnel;

7. Develop further categories in the personnel system to identify clearly the skills that would be necessary for the realignment of the system;

8. Use Federal Supply Classes instead of commodities in the depot model to improve the accuracy of the results;

9. Split up the bin, bulk, and carousel storage requirements for use in the depot model;

10. Create a matrix generator that could be used to input all the data to the depot model;

11. Develop some data on the mechanized material handling equipment requirement at the depots;

12. Expand the depot model to include all commodities except fuel and all 57 customers;

13. Use a more sophisticated computer package such as the University of Arizona package on the Wright-Patterson AFB CDC system, for further development of the depot model;

14. Widen the scope of the models so that they could be used in mobilization planning or war planning.

15. Investigate the potential of formulating the models as multiobjective or goal programming models. These models would identify various specific objectives related to reallocation under emergency situations and take them all into account when developing planning factors.

These recommendations vary in degrees of difficulty, but if they all could be implemented in some form they would greatly enhance the DLA planning capability.

# Appendix A: Sources of Data

## Data for the ICP Model

*Source: Technology Division, Office of Telecommunications and Information Systems*

| Data Element | Definition |
|---|---|
| ccp | Cost of acquiring ADP equipment (disk drive) |
| aac | Additional ADP capacity per additional unit of ADP equipment (disk drive) |
| $cac_j$ | Current excess ADP capacity at $ICP_j$ |
| cd | Cost of acquiring digital communications circuits |
| $cdc_j$ | Current excess digital communications capacity at $ICP_j$ |
| adc | Cost of additional communications circuits |

Source: Installations Division, Office of Installations Services and Environmental Protection

| Data Element | Definition |
|---|---|
| isp | Space required per person (in sq. ft.) |
| $rsc_j$ | Cost to add an office space unit at $ICP_j$ |
| $sc_j$ | Space available at $ICP_j$ (in sq. ft.) |
| asu | Additional space per added space unit (in sq. ft.) |
| $cs_j$ | Cost of additional covered storage space units required at depot j |

Source: Survey and Standards Division, Office of Comptroller

| Data Element | Definition |
|---|---|
| $TRP_j$ | Total authorized personnel (military and civilian) available at each $ICP_j$ |

| Data Element | Definition |
|---|---|
| $IM_j$ | Total of inventory management specialists at each $ICP_j$ (2010 job series) |
| $BUY_j$ | Total of contracting and procurement specialists at each $ICP_j$ (1102 job series) |
| $CIV_j$ | Total authorized personnel in the civilian personnel office at each $ICP_j$ |

Source: Stock Fund Division, Office of Comptroller

| Data Elements | Definition |
|---|---|
| $ALT\$_j$ | Dollars invested in stock to cover ALT at each $ICP_j$ |

Source: Operations Research and Economic Analysis Office, Office of Plans, Policies and Programs

| Data Element | Definition |
|---|---|
| $ITM_j$ | Total number of items managed at each $ICP_j$ |
| $SD\$_j$ | Total dollars invested in safety level at each $ICP_j$ (for both 90% and 92% goals) |
| $ct_j$ | Cost to transfer a person from one ICP to another ICP |

Source: Employment and Management Assistance Division, DASC Office of Civilian Personnel

| Data Element | Definition |
|---|---|
| $hir_k$ | Cost to hire a person in area k at an ICP (monthly salary of GS worker at average grade at step 5 level within civilian personnel office) |

Data for the Depot Model

Source: Depot Operations Division, Directorate of Supply Operations

| Data Element | Definition |
|---|---|
| $csc_j$ | Maximum amount of covered storage space available at depot j (in sq. ft.) |
| asp | Additional space available per additional storage unit (in sq. ft.) |
| cbn | Cost of acquiring a bin for storage |
| $cbc_j$ | Current number of bins at depot j |
| $cf_j$ | Cost of acquiring specialized mechanized material handling equipment for depot j |
| $cnc_j$ | Current specialized mechanized material handling equipment available at depot j |

Source: Larry Stein Realty, Dayton, Ohio

| Data Element | Definition |
|---|---|
| $cs_j$, j=6,7,8,9,10 | Cost of additional rented covered storage space units required at depot j |

Source: Survey and Standards Division, Office of Comptroller

| Data Element | Definition |
|---|---|
| $cpc_j$ | Total authorized personnel (military and civilian) available at depot j |
| $CIV_j$ | Total authorized personnel in the civilian personnel office at each depot j |

Source: Installations Division, Office of Installation Services and Environmental Protection

| Data Element | Definition |
|---|---|
| $cs_j$, j=1,2,3,4,5 | Cost of additional purchased covered storage space units required at depot j |

Source: Supply Management Division, Directorate of Supply Operations

| Data Element | Definition |
|---|---|
| $N_{ij}$ | Commodity restriction, total weight (in hundredweight) shipped of commodity i from depot j, if that commodity is shipped from that depot |

| Data Element | Definition |
|---|---|
| $M_{ijk}$ | Customer restriction, total weight (in hundredweight) demanded of commodity i from depot j by customer k, if that customer is served by that depot for that commodity |

Source: Transportation Division, Directorate of Supply Operations

| Data Element | Definition |
|---|---|
| $c_{ijk}$ | Outbound transportation cost (per hundredweight) of shipping commodity i from depot j to customer k |
| $TS_{ij}$ | Weight (in hundredweight) shipped of each commodity i from each depot j |
| $dem_{ik}$ | Weight (in hundredweight) of demand of commodity i from customer k |

Source: Operations Research and Economic Analysis Office, Office of Plans, Policies and Programs

| Data Element | Definition |
|---|---|
| $ct_j$ | Cost to transfer a person from one depot to another depot |

Source: Employment and Management Assistance Division, DASC Office of Civilian Personnel

| Data Element | Definition |
|---|---|
| ch | Cost to hire a person at a depot (monthly salary of GS worker at average grade at step 5 level within civilian personnel office) |

# Appendix B: Data Elements

## ICP Data Elements

| Data Element | | Value | | |
|---|---|---|---|---|
| aac | | 1.0 | | |
| asu | | 120000. | | |
| $cac_j$ | | 0.0 (all ICP's) | | |
| ccp | | 125000. | | |
| $cp_{jk}$ | | | | |
| | | Area 1 (IM) | Area 2 (Buyer) | Area 3 (Cmd/Sup) |
| | DCSC | 180 | 413 | 2155 |
| | DESC | 206 | 248 | 1765 |
| | DGSC | 122 | 292 | 1580 |
| | DISC | 254 | 254 | 1605 |
| $cpc_k$ | | Taken from $cp_{jk}$ data depending on ICP eliminated | | |
| $ct_j$ | | 30000. (all ICP's) | | |
| $hir_k$ | | 1793. (all ICP's) | | |
| isp | | 175. | | |
| itm | DCSC | 374710. | | |
| | DESC | 821499. | | |
| | DGSC | 246777. | | |
| | DISC | 715471. | | |
| $pby_j$ | DCSC | 31632. | | |
| | DESC | 46384. | | |
| | DGSC | 37363. | | |
| | DISC | 34454. | | |

Components:

Administrative leadtime investment:

DCSC 34836955 = 268700000 X (.05 X .085 + .95 X .132)

DESC 30675190 = 236600000 X (.05 X .085 + .95 X .132)

DGSC 29093460 = 224400000 X (.05 X .085 + .95 X .132)

DISC 23337000 = 180000000 X (.05 X .085 + .95 X .132)

Training hours:

780 (10 hours per week for 78 weeks)

Total hours:

DCSC 859040

DESC 515840

DGSC 607360

DISC 528320

(number of buyers times 2080 hours per year)

| Data Element | | Value |
|---|---|---|
| $pim_j$ | DCSC | 66535. |
| | DESC | 50237. |
| | DGSC | 82233. |
| | DISC | 44686. |

Components:

Safety level investment:

DCSC 31937000.

DESC 27597000.

DGSC 26753000.

DISC 30267000.

(difference between a 92% supply availability goal and a 90% supply availability goal)

Training hours:

780 (10 hours per week for 78 weeks)

Total hours:

DCSC 374400

DESC 428480

DGSC 253760

DISC 528320

(number of item managers times 2080 hours per year)

| Data Element | | Value |
|---|---|---|
| $prh_k$ | | .5 (all ICP's) |
| $prt_k$ | | .2 (all ICP's) |
| $rsc_j$ | | 9600000. (all ICP's) |
| $sc_j$ | | 0.0 (all ICP's) |
| vfa | DCSC | .000027 |
| | DESC | .000012 |
| | DGSC | .000041 |
| | DISC | .000014 |

(10 disk drives at each ICP divided by the number of items managed at each ICP)

<u>Depot Data Elements</u>

| Data Element | Value |
|---|---|
| aac | 1.0 |
| asp | 120000. |
| $c_{ijk}$ | |

Mechanicsburg

| | | | | | |
|---|---|---|---|---|---|
| $c_{111}$ | 22.49 | $c_{113}$ | 21.79 | $c_{117}$ | 15.54 |
| $c_{112}$ | 18.59 | $c_{115}$ | 41.09 | $c_{1110}$ | 3.46 |

| | | | | | |
|---|---|---|---|---|---|
| $C_{211}$ | 96.00 | $C_{313}$ | 10.83 | $C_{414}$ | 22.49 |
| $C_{212}$ | 78.13 | $C_{315}$ | 13.87 | $C_{415}$ | 28.65 |
| $C_{214}$ | 137.00 | $C_{317}$ | 11.01 | $C_{416}$ | 22.69 |
| $C_{2110}$ | 11.07 | $C_{3110}$ | 4.59 | $C_{417}$ | 17.45 |
| $C_{311}$ | 8.22 | $C_{411}$ | 12.52 | $C_{4110}$ | 5.88 |
| $C_{312}$ | 7.41 | $C_{412}$ | 12.25 | | |

Richmond

| | | | | | |
|---|---|---|---|---|---|
| $C_{222}$ | 3.54 | $C_{422}$ | 2.22 | $C_{425}$ | 13.79 |
| $C_{223}$ | 34.92 | $C_{423}$ | 4.78 | $C_{426}$ | 25.61 |
| $C_{224}$ | 43.32 | $C_{424}$ | 11.90 | $C_{427}$ | 12.77 |
| $C_{225}$ | 52.99 | | | | |

Columbus

| | | | | | |
|---|---|---|---|---|---|
| $C_{133}$ | 15.87 | $C_{137}$ | 19.61 | $C_{335}$ | 50.03 |
| $C_{134}$ | 18.28 | $C_{333}$ | 37.69 | $C_{336}$ | 29.90 |
| $C_{135}$ | 39.73 | $C_{334}$ | 20.14 | $C_{337}$ | 30.34 |
| $C_{136}$ | 27.99 | | | | |

Ogden

| | | | | | |
|---|---|---|---|---|---|
| $C_{143}$ | 33.08 | $C_{247}$ | 20.30 | $C_{349}$ | 4.75 |
| $C_{145}$ | 31.39 | $C_{248}$ | 11.99 | $C_{444}$ | 14.69 |
| $C_{146}$ | 15.35 | $C_{249}$ | 4.09 | $C_{445}$ | 19.25 |
| $C_{147}$ | 12.64 | $C_{343}$ | 33.51 | $C_{446}$ | 13.27 |
| $C_{148}$ | 25.56 | $C_{345}$ | 49.03 | $C_{447}$ | 10.13 |
| $C_{149}$ | 11.62 | $C_{346}$ | 13.85 | $C_{448}$ | 12.90 |
| $C_{245}$ | 79.16 | $C_{347}$ | 11.01 | $C_{449}$ | .15 |
| $C_{246}$ | 16.43 | $C_{348}$ | 15.23 | | |

Tracy

| | | | | | |
|---|---|---|---|---|---|
| $C_{153}$ | 33.00 | $C_{2511}$ | .96 | $C_{454}$ | 44.62 |
| $C_{155}$ | 44.74 | $C_{353}$ | 27.66 | $C_{455}$ | 28.11 |
| $C_{157}$ | 22.39 | $C_{355}$ | 33.69 | $C_{456}$ | 45.76 |
| $C_{159}$ | 8.87 | $C_{357}$ | 19.85 | $C_{457}$ | 19.91 |
| $C_{1511}$ | 2.43 | $C_{359}$ | 15.01 | $C_{459}$ | 10.16 |
| $C_{259}$ | 62.63 | $C_{3511}$ | 2.79 | $C_{4511}$ | 2.53 |

(median shipping cost per hundredweight to states of countries in each customer area)

| Data Element | | Value | |
|---|---|---|---|
| $cac_j$ | | 0.0 | (all depots) |
| ccp | | 125000. | |
| ch | | 1793. | |
| $cpc_j$ | | 0.0 | (all depots) |
| $cs_j$ | | | |
| Purchase | | | |
| j = 1,2,3,4,5 | | 4800000. | (all depots) |
| Rent | | | |
| j = 6,7,8,9,10 | DDMT | 330000. | |
| | DGSC | 240000. | |
| | DCSC | 300000. | |
| | DDOU | 288000. | |
| | DDTC | 288000. | |
| $csc_j$ | DDMT | 0.0 | |
| | DGSC | 55950. | |
| | DCSC | 8600. | |
| | DDOU | 488200. | |
| | DDTC | 48800. | |

$ct_j$ 30000. (all depots)

$dem_{ik}$

| | | | | | |
|---|---|---|---|---|---|
| $dem_{11}$ | 108.55 | $dem_{44}$ | 6092.65 | $dem_{38}$ | 153.74 |
| $dem_{21}$ | 0.0 | $dem_{15}$ | 1785.83 | $dem_{48}$ | 286.83 |
| $dem_{31}$ | 287.66 | $dem_{25}$ | 0.0 | $dem_{19}$ | 301.55 |
| $dem_{41}$ | 515.20 | $dem_{35}$ | 2518.15 | $dem_{29}$ | 0.0 |
| $dem_{12}$ | 447.35 | $dem_{45}$ | 12781.22 | $dem_{39}$ | 1494.70 |
| $dem_{22}$ | 0.0 | $dem_{16}$ | 25.21 | $dem_{49}$ | 3546.13 |
| $dem_{32}$ | 2006.60 | $dem_{26}$ | 0.0 | $dem_{110}$ | 992.04 |
| $dem_{42}$ | 3540.70 | $dem_{36}$ | 181.21 | $dem_{210}$ | 0.0 |
| $dem_{13}$ | 1696.80 | $dem_{46}$ | 1346.29 | $dem_{310}$ | 2452.88 |
| $dem_{23}$ | 0.0 | $dem_{17}$ | 2400.99 | $dem_{410}$ | 5164.03 |
| $dem_{33}$ | 4641.10 | $dem_{27}$ | 0.0 | $dem_{111}$ | 451.47 |
| $dem_{43}$ | 15513.35 | $dem_{37}$ | 4994.38 | $dem_{211}$ | 0.0 |
| $dem_{14}$ | 488.32 | $dem_{47}$ | 19091.96 | $dem_{311}$ | 613.53 |
| $dem_{24}$ | 0.0 | $dem_{18}$ | 58.27 | $dem_{411}$ | 2019.61 |
| $dem_{34}$ | 995.19 | $dem_{28}$ | 0.0 | | |

(demand in hundredweight)

$M_{ijk}$

The following customer restrictions all equal zero:

Mechanicsburg

| | | | | |
|---|---|---|---|---|
| $M_{114}$ | $M_{213}$ | $M_{219}$ | $M_{319}$ | $M_{4111}$ |
| $M_{116}$ | $M_{215}$ | $M_{2111}$ | $M_{3111}$ | |
| $M_{118}$ | $M_{216}$ | $M_{314}$ | $M_{4103}$ | |
| $M_{119}$ | $M_{217}$ | $M_{316}$ | $M_{4108}$ | |
| $M_{1111}$ | $M_{218}$ | $M_{318}$ | $M_{4109}$ | |

Richmond

| | | | | | |
|---|---|---|---|---|---|
| $M_{221}$ | $M_{227}$ | $M_{229}$ | $M_{2211}$ | $M_{428}$ | $M_{4210}$ |
| $M_{226}$ | $M_{228}$ | $M_{2210}$ | $M_{421}$ | $M_{429}$ | $M_{4211}$ |

Columbus

| | | | | | |
|---|---|---|---|---|---|
| $M_{131}$ | $M_{138}$ | $M_{1310}$ | $M_{331}$ | $M_{338}$ | $M_{3310}$ |
| $M_{132}$ | $M_{139}$ | $M_{1311}$ | $M_{332}$ | $M_{339}$ | $M_{3311}$ |

Ogden

| | | | | | | |
|---|---|---|---|---|---|---|
| $M_{141}$ | $M_{1410}$ | $M_{242}$ | $M_{2410}$ | $M_{342}$ | $M_{3411}$ | $M_{443}$ |
| $M_{142}$ | $M_{1411}$ | $M_{243}$ | $M_{2411}$ | $M_{344}$ | $M_{441}$ | $M_{4410}$ |
| $M_{144}$ | $M_{241}$ | $M_{244}$ | $M_{341}$ | $M_{3410}$ | $M_{442}$ | $M_{4411}$ |

Tracy

| | | | | | | |
|---|---|---|---|---|---|---|
| $M_{151}$ | $M_{158}$ | $M_{253}$ | $M_{257}$ | $M_{352}$ | $M_{3510}$ | $M_{458}$ |
| $M_{152}$ | $M_{1510}$ | $M_{254}$ | $M_{258}$ | $M_{354}$ | $M_{451}$ | $M_{4510}$ |
| $M_{154}$ | $M_{251}$ | $M_{255}$ | $M_{2510}$ | $M_{356}$ | $M_{452}$ | |
| $M_{156}$ | $M_{252}$ | $M_{256}$ | $M_{351}$ | $M_{358}$ | $M_{453}$ | |

The customer restrictions listed above are expressed as cost coefficients of 10.000,000,000 in the objective function. All other values are allowed to equal the total demand from the customer.

$N_{ij}$

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $N_{11}$ | 8786.38 | $N_{32}$ | 0.0 | $N_{14}$ | 8786.38 | $N_{35}$ | 20339.14 |
| $N_{21}$ | 0.0 | $N_{42}$ | 69897.97 | $N_{24}$ | 0.0 | $N_{45}$ | 69897.97 |
| $N_{31}$ | 20339.14 | $N_{13}$ | 8786.38 | $N_{34}$ | 20339.14 | | |
| $N_{41}$ | 69897.97 | $N_{23}$ | 0.0 | $N_{44}$ | 69897.97 | | |
| $N_{12}$ | 0.0 | $N_{33}$ | 20339.14 | $N_{15}$ | 8786.38 | | |
| $N_{22}$ | 0.0 | $N_{43}$ | 0.0 | $N_{25}$ | 0.0 | | |

Commodity restrictions $N_{12}$, $N_{32}$, $N_{23}$, and $N_{43}$ are expressed as cost coefficients of 20,000,000,000 in the objective function.

| | |
|---|---|
| pa | 458 |
| $ufa_i$ | .000050 (all commodities) |

Component:

5 disk drives at Memphis divided by 99023.49, the total weight (in hundredweight) of all commodities shipped from Memphis.

| | |
|---|---|
| $ufp_i$ | .0231 (all commodities) |

Component:

2288 total personnel at Memphis divided by 99023.49, the total weight (in hundredweight) of all commodities shipped from Memphis.

| | |
|---|---|
| $ufs_i$ | 20.75 (all commodities) |

Component:

2055000 square feet of occupied covered storage space at Memphis divided by 99023.49, the total weight (in hundredweight) of all commodities shipped from Memphis.

```
TITLE
DCSC OUT ICP MODEL
REGULAR
VARIABLES
Z1 TO Z3 D1 TO D3 ADP1 TO ADP3 PH11 TO PH13 PH21 TO PH23 PH31 TO PH33
O11 TO O13 O21 TO O23 O31 TO O33 NSP1 TO NSP3
MINIMIZE
125000ADP1 + 125000ADP2 + 125000ADP3 + 0.0D1 + 0.0D2 + 0.0D3 +
9600000NSP1 + 9600000NSP2 + 9600000NSP3 + 52030.0PH11 +
46479.0PH21 + 84026.0PH31 + 48177.0PH12 + 36247.0PH22 + 39156.0PH32 +
1793.0PH13 + 1793.0PH23 + 1793.0PH33 + 30000.0O11 + 30000.0O12 +
30000.0O13 + 30000.0O21 + 30000.0O22 + 30000.0O23 + 30000.0O31 +
30000.0O32 + 30000.0O33
CONSTRAINTS
Z1 + Z2 + Z3 = 374710
.000027Z1 - ADP1 .LE. 0
.000027Z2 - ADP2 .LE. 0
.000027Z3 - ADP3 .LE. 0
175O11 + 175O12 + 175O13 + 175PH11 + 175PH12 + 175PH13 -
 120000NSP1 .LE. 0.0
175O21 + 175O22 + 175O23 + 175PH21 + 175PH22 + 175PH23 -
 120000NSP2 .LE. 0.0
175O31 + 175O32 + 175O33 + 175PH31 + 175PH32 + 175PH33 -
 120000NSP3 .LE. 0.0
.0Z1 - 0D1 .LE. 0
.0Z2 - 0D2 .LE. 0
.0Z3 - 0D3 .LE. 0
O11 + O21 + O31 + PH11 + PH21 + PH31 .GE. 180
O12 + O22 + O32 + PH12 + PH22 + PH32 .GE. 413
O13 + O23 + O33 + PH13 + PH23 + PH33 .GE. 2155
O11 + O21 + O31 .LE. 37
O12 + O22 + O32 .LE. 83
O13 + O23 + O33 .LE. 432
PH11 .LE. 104
PH12 .LE. 125
PH13 .LE. 883
PH21 .LE. 128
PH22 .LE. 128
PH23 .LE. 803
PH31 .LE. 62
PH32 .LE. 147
PH33 .LE. 791
O11 - 0.436O12 + PH11 - 0.436PH12 = 0.0
O21 - 0.436O22 + PH21 - 0.436PH22 = 0.0
O31 - 0.436O32 + PH31 - 0.436PH32 = 0.0
O12 - 0.192O13 + PH12 - 0.192PH13 = 0.0
O22 - 0.192O23 + PH22 - 0.192PH23 = 0.0
O32 - 0.192O33 + PH32 - 0.192PH33 = 0.0
O11 + PH11 - .000480Z1 .GE. 0.0
O21 + PH21 - .000480Z2 .GE. 0.0
O31 + PH31 - .000480Z3 .GE. 0.0
BOUNDS
ADP1 .LE. 10.
ADP2 .LE. 10.
ADP3 .LE. 10.
NSP1 .LE. 10.
NSP2 .LE. 10.
NSP3 .LE. 10.
RNGOBJ
RNGRHS
PRINT
CHECK
OPTIMIZE
STOP
```

```
TITLE
DESC OUT ICP MODEL
REGULAR
VARIABLES
Z1 TO Z3 D1 TO D3 ADP1 TO ADP3 PH11 TO PH13 PH21 TO PH23 PH31 TO PH33
O11 TO O13 O21 TO O23 O31 TO O33 NSP1 TO NSP3
MINIMIZE
125000ADP1 + 125000ADP2 + 125000ADP3 + 0.0D1 + 0.0D2 + 0.0D3 +
9600000NSP1 + 9600000NSP2 + 9600000NSP3 + 46479.0PH11 +
84026.0PH21 + 68328.0PH31 + 36247.0PH12 + 39156.0PH22 + 33425.0PH32 +
1793.0PH13 + 1793.0PH23 + 1793.0PH33 + 30000.0O11 + 30000.0O12 +
30000.0O13 + 30000.0O21 + 30000.0O22 + 30000.0O23 + 30000.0O31 +
30000.0O32 + 30000.0O33
CONSTRAINTS
Z1 + Z2 + Z3 = 821499
.000012Z1 - ADP1 .LE. 0
.000012Z2 - ADP2 .LE. 0
.000012Z3 - ADP3 .LE. 0
175O11 + 175O12 + 175O13 + 175PH11 + 175PH12 + 175PH13 -
 120000NSP1 .LE. 0.0
175O21 + 175O22 + 175O23 + 175PH21 + 175PH22 + 175PH23 -
 120000NSP2 .LE. 0.0
175O31 + 175O32 + 175O33 + 175PH31 + 175PH32 + 175PH33 -
 120000NSP3 .LE. 0.0
.0Z1 - OD1 .LE. 0
.0Z2 - OD2 .LE. 0
.0Z3 - OD3 .LE. 0
O11 + O21 + O31 + PH11 + PH21 + PH31 .GE. 206
O12 + O22 + O32 + PH12 + PH22 + PH32 .GE. 248
O13 + O23 + O33 + PH13 + PH23 + PH33 .GE. 1765
O11 + O21 + O31 .LE. 42
O12 + O22 + O32 .LE. 50
O13 + O23 + O33 .LE. 354
PH11 .LE. 128
PH12 .LE. 128
PH13 .LE. 803
PH21 .LE. 62
PH22 .LE. 147
PH23 .LE. 791
PH31 .LE. 91
PH32 .LE. 207
PH33 .LE. 1078
O11 - 0.831O12 + PH11 - 0.831PH12 = 0.0
O21 - 0.831O22 + PH21 - 0.831PH22 = 0.0
O31 - 0.831O32 + PH31 - 0.831PH32 = 0.0
O12 - 0.141O13 + PH12 - 0.141PH13 = 0.0
O22 - 0.141O23 + PH22 - 0.141PH23 = 0.0
O32 - 0.141O33 + PH32 - 0.141PH33 = 0.0
O11 + PH11 - .000251Z1 .GE. 0.0
O21 + PH21 - .000251Z2 .GE. 0.0
O31 + PH31 - .000251Z3 .GE. 0.0
BOUNDS
ADP1 .LE. 10.
ADP2 .LE. 10.
ADP3 .LE. 10.
NSP1 .LE. 10.
NSP2 .LE. 10.
NSP3 .LE. 10.
RNGOBJ
RNGRHS
PRINT
CHECK
OPTIMIZE
STOP
```

```
TITLE
DGSC OUT ICP MODEL
REGULAR
VARIABLES
Z1 TO Z3 D1 TO D3 ADP1 TO ADP3 PH11 TO PH13 PH21 TO PH23 PH31 TO PH33
011 TO 013 021 TO 023 031 TO 033 NSP1 TO NSP3
MINIMIZE
125000ADP1 + 125000ADP2 + 125000ADP3 + 0.0D1 + 0.0D2 + 0.0D3 +
9600000NSP1 + 9600000NSP2 + 9600000NSP3 + 52030.0PH11 +
46479.0PH21 + 68328.0PH31 + 48177.0PH12 + 36247.0PH22 + 33425.0PH32 +
1793.0PH13 + 1793.0PH23 + 1793.0PH33 + 30000.0011 + 30000.0012 +
30000.0013 + 30000.0021 + 30000.0022 + 30000.0023 + 30000.0031 +
30000.0032 + 30000.0033
CONSTRAINTS
Z1 + Z2 + Z3 = 246777
.000041Z1 - ADP1 .LE. 0
.000041Z2 - ADP2 .LE. 0
.000041Z3 - ADP3 .LE. 0
175011 + 175012 + 175013 + 175PH11 + 175PH12 + 175PH13 -
 120000NSP1 .LE. 0.0
175021 + 175022 + 175023 + 175PH21 + 175PH22 + 175PH23 -
 120000NSP2 .LE. 0.0
175031 + 175032 + 175033 + 175PH31 + 175PH32 + 175PH33 -
 120000NSP3 .LE. 0.0
.0Z1 - 0D1 .LE. 0
.0Z2 - 0D2 .LE. 0
.0Z3 - 0D3 .LE. 0
011 + 021 + 031 + PH11 + PH21 + PH31 .GE. 122
012 + 022 + 032 + PH12 + PH22 + PH32 .GE. 292
013 + 023 + 033 + PH13 + PH23 + PH33 .GE. 1580
011 + 021 + 031 .LE. 25
012 + 022 + 032 .LE. 59
013 + 023 + 033 .LE. 317
PH11 .LE. 104
PH12 .LE. 125
PH13 .LE. 883
PH21 .LE. 128
PH22 .LE. 128
PH23 .LE. 803
PH31 .LE. 91
PH32 .LE. 207
PH33 .LE. 1078
011 - 0.418012 + PH11 - 0.418PH12 = 0.0
021 - 0.418022 + PH21 - 0.418PH22 = 0.0
031 - 0.418032 + PH31 - 0.418PH32 = 0.0
012 - 0.185013 + PH12 - 0.185PH13 = 0.0
022 - 0.185023 + PH22 - 0.185PH23 = 0.0
032 - 0.185033 + PH32 - 0.185PH33 = 0.0
011 + PH11 - .000494Z1 .GE. 0.0
021 + PH21 - .000494Z2 .GE. 0.0
031 + PH31 - .000494Z3 .GE. 0.0
BOUNDS
ADP1 .LE. 10.
ADP2 .LE. 10.
ADP3 .LE. 10.
NSP1 .LE. 10.
NSP2 .LE. 10.
NSP3 .LE. 10.
RNGOBJ
RNGRHS
PRINT
CHECK
OPTIMIZE
STOP
```

```
TITLE
DISC OUT ICP MODEL
REGULAR
VARIABLES
Z1 TO Z3 D1 TO D3 ADP1 TO ADP3 PH11 TO PH13 PH21 TO PH23 PH31 TO PH33
O11 TO O13 O21 TO O23 O31 TO O33 NSP1 TO NSP3
MINIMIZE
125000ADP1 + 125000ADP2 + 125000ADP3 + 0.0D1 + 0.0D2 + 0.0D3 +
9600000NSP1 + 9600000NSP2 + 9600000NSP3 + 52030.0PH11 +
84026.0PH21 + 68328.0PH31 + 48177.0PH12 + 39156.0PH22 + 33425.0PH32 +
1793.0PH13 + 1793.0PH23 + 1793.0PH33 + 30000.0O11 + 30000.0O12 +
30000.0O13 + 30000.0O21 + 30000.0O22 + 30000.0O23 + 30000.0O31 +
30000.0O32 + 30000.0O33
CONSTRAINTS
Z1 + Z2 + Z3 = 715471
.000014Z1 - ADP1 .LE. 0
.000014Z2 - ADP2 .LE. 0
.000014Z3 - ADP3 .LE. 0
175O11 + 175O12 + 175O13 + 175PH11 + 175PH12 + 175PH13 -
 120000NSP1 .LE. 0.0
175O21 + 175O22 + 175O23 + 175PH21 + 175PH22 + 175PH23 -
 120000NSP2 .LE. 0.0
175O31 + 175O32 + 175O33 + 175PH31 + 175PH32 + 175PH33 -
 120000NSP3 .LE. 0.0
.0Z1 - OD1 .LE. 0
.0Z2 - OD2 .LE. 0
.0Z3 - OD3 .LE. 0
O11 + O21 + O31 + PH11 + PH21 + PH31 .GE. 254
O12 + O22 + O32 + PH12 + PH22 + PH32 .GE. 254
O13 + O23 + O33 + PH13 + PH23 + PH33 .GE. 1605
O11 + O21 + O31 .LE. 51
O12 + O22 + O32 .LE. 51
O13 + O23 + O33 .LE. 322
PH11 .LE. 104
PH12 .LE. 125
PH13 .LE. 883
PH21 .LE. 62
PH22 .LE. 147
PH23 .LE. 791
PH31 .LE. 91
PH32 .LE. 207
PH33 .LE. 1078
O11 - 1.000O12 + PH11 - 1.000PH12 = 0.0
O21 - 1.000O22 + PH21 - 1.000PH22 = 0.0
O31 - 1.000O32 + PH31 - 1.000PH32 = 0.0
O12 - 0.158O13 + PH12 - 0.158PH13 = 0.0
O22 - 0.158O23 + PH22 - 0.158PH23 = 0.0
O32 - 0.158O33 + PH32 - 0.158PH33 = 0.0
O11 + PH11 - .000355Z1 .GE. 0.0
O21 + PH21 - .000355Z2 .GE. 0.0
O31 + PH31 - .000355Z3 .GE. 0.0
BOUNDS
ADP1 .LE. 10.
ADP2 .LE. 10.
ADP3 .LE. 10.
NSP1 .LE. 10.
NSP2 .LE. 10.
NSP3 .LE. 10.
RNGOBJ
RNGRHS
PRINT
CHECK
OPTIMIZE
STOP
```

# Appendix D: Depot Program

```
TITLE
DDMT OUT DEPOT MODEL
DUAL
VARIABLES
X1101 TO X1111 X2101 TO X2111 X3101 TO X3111 X4101 TO X4111
X1201 TO X1211 X2201 TO X2211 X3201 TO X3211 X4201 TO X4211
X1301 TO X1311 X2301 TO X2311 X3301 TO X3311 X4301 TO X4311
X1401 TO X1411 X2401 TO X2411 X3401 TO X3411 X4401 TO X4411
X1501 TO X1511 X2501 TO X2511 X3501 TO X3511 X4501 TO X4511
SP1 TO SP10 ADP1 TO ADP5 PT1 TO PT5 PH1 TO PH5
D1 TO D5 BIN1 TO BIN5 MHE1 TO MHE5
MINIMIZE
22.49X1101 + 18.59X1102 + 21.79X1103 + 10000000000X1104 +
41.09X1105 + 10000000000X1106 + 15.54X1107 + 10000000000X1108 +
10000000000X1109 + 3.46X1110 + 10000000000X1111 +
96.00X2101 + 78.13X2102 + 10000000000X2103 + 137.00X2104 +
10000000000X2105 + 10000000000X2106 + 10000000000X2107 +
10000000000X2108 + 10000000000X2109 + 11.07X2110 +
10000000000X2111 +
8.22X3101 + 7.41X3102 + 10.83X3103 + 10000000000X3104 +
13.87X3105 + 10000000000X3106 + 11.01X3107 +
10000000000X3108 + 10000000000X3109 + 4.59X3110 +
10000000000X3111 +
12.52X4101 + 12.25X4102 + 10000000000X4103 + 22.49X4104 +
28.65X4105 + 22.69X4106 + 17.45X4107 + 10000000000X4108 +
10000000000X4109 + 5.88X4110 + 10000000000X4111 +
20000000000X1201 + 20000000000X1202 + 20000000000X1203 +
20000000000X1204 + 20000000000X1205 + 20000000000X1206 +
20000000000X1207 + 20000000000X1208 + 20000000000X1209 +
20000000000X1210 + 20000000000X1211 +
10000000000X2201 + 3.54X2202 + 34.92X2203 + 43.32X2204 +
52.99X2205 + 10000000000X2206 + 10000000000X2207 +
10000000000X2208 + 10000000000X2209 + 10000000000X2210 +
10000000000X2211 +
20000000000X3201 + 20000000000X3202 + 20000000000X3203 +
20000000000X3204 + 20000000000X3205 + 20000000000X3206 +
20000000000X3207 + 20000000000X3208 + 20000000000X3209 +
20000000000X3210 + 20000000000X3211 +
10000000000X4201 + 2.22X4202 + 4.78X4203 + 11.90X4204 +
13.79X4205 + 25.61X4206 + 12.77X4207 + 10000000000X4208 +
10000000000X4209 + 10000000000X4210 + 10000000000X4211 +
10000000000X1301 + 10000000000X1302 + 15.87X1303 +
18.28X1304 + 39.73X1305 + 27.99X1306 + 19.61X1307 +
10000000000X1308 + 10000000000X1309 + 10000000000X1310 +
10000000000X1311 +
20000000000X2301 + 20000000000X2302 + 20000000000X2303 +
20000000000X2304 + 20000000000X2305 + 20000000000X2306 +
20000000000X2307 + 20000000000X2308 + 20000000000X2309 +
20000000000X2310 + 20000000000X2311 +
10000000000X3301 + 10000000000X3302 + 37.69X3303 + 20.14X3304 +
50.03X3305 + 29.90X3306 + 30.34X3307 + 10000000000X3308 +
10000000000X3309 + 10000000000X3310 + 10000000000X3311 +
20000000000X4301 + 20000000000X4302 + 20000000000X4303 +
20000000000X4304 + 20000000000X4305 + 20000000000X4306 +
20000000000X4307 + 20000000000X4308 + 20000000000X4309 +
20000000000X4310 + 20000000000X4311 +
10000000000X1401 + 10000000000X1402 + 33.08X1403 +
10000000000X1404 + 31.39X1405 + 15.35X1406 + 12.64X1407 +
25.56X1408 + 11.62X1409 + 10000000000X1410 +
10000000000X1411 +
10000000000X2401 + 10000000000X2402 + 10000000000X2403 +
10000000000X2404 + 79.16X2405 + 16.43X2406 + 20.30X2407 +
11.99X2408 + 4.09X2409 + 10000000000X2410 + 10000000000X2411 +
10000000000X3401 + 10000000000X3402 + 33.51X3403 +
10000000000X3404 + 48.03X3405 + 13.85X3406 + 11.01X3407 +
```

```
15.23X3408 + 4.75X3409 + 10000000000X3410 + 10000000000X3411 +
10000000000X4401 + 10000000000X4402 + 10000000000X4403 +
14.69X4404 + 19.25X4405 + 13.27X4406 + 10.13X4407 +
12.90X4408 + .15X4409 + 10000000000X4410 + 10000000000X4411 +
10000000000X1501 + 10000000000X1502 + 33.00X1503 +
10000000000X1504 + 44.74X1505 + 10000000000X1506 +
22.39X1507 + 10000000000X1508 + 8.87X1509 +
10000000000X1510 + 2.43X1511 +
10000000000X2501 + 10000000000X2502 + 10000000000X2503 +
10000000000X2504 + 10000000000X2505 + 10000000000X2506 +
10000000000X2507 + 10000000000X2508 + 62.63X2509 +
10000000000X2510 + .96X2511 +
10000000000X3501 + 10000000000X3502 + 27.66X3503 +
10000000000X3504 + 33.69X3505 + 10000000000X3506 +
19.85X3507 + 10000000000X3508 + 15.01X3509 +
10000000000X3510 + 2.79X3511 +
10000000000X4501 + 10000000000X4502 + 10000000000X4503 +
44.62X4504 + 28.11X4505 + 45.76X4506 + 19.91X4507 +
10000000000X4508 + 10.16X4509 + 10000000000X4510 + 2.53X4511 +
4800000.SP1 + 4800000.SP2 + 4800000.SP3 + 4800000.SP4 +
4800000.SP5 + 125000.ADP1 + 125000.ADP2 + 125000.ADP3 +
125000.ADP4 + 125000.ADP5 + 30000.PT1 + 30000.PT2 + 30000.PT3 +
30000.PT4 + 30000.PT5 + 1793.PH1 + 1793.PH2 + 1793.PH3 +
1793.PH4 + 1793.PH5 + 330000.SP6 + 240000.SP7 + 300000.SP8 +
288000.SP9 + 288000.SP10
CONSTRAINTS
X1101 + X1201 + X1301 + X1401 + X1501 = 108.55
X2101 + X2201 + X2301 + X2401 + X2501 = 0.0
X3101 + X3201 + X3301 + X3401 + X3501 = 287.66
X4101 + X4201 + X4301 + X4401 + X4501 = 515.20
X1102 + X1202 + X1302 + X1402 + X1502 = 477.35
X2102 + X2202 + X2302 + X2402 + X2502 = 0.0
X3102 + X3202 + X3302 + X3402 + X3502 = 2006.60
X4102 + X4202 + X4302 + X4402 + X4502 = 3540.70
X1103 + X1203 + X1303 + X1403 + X1503 = 1696.80
X2103 + X2203 + X2303 + X2403 + X2503 = 0.0
X3103 + X3203 + X3303 + X3403 + X3503 = 4641.10
X4103 + X4203 + X4303 + X4403 + X4503 = 15513.35
X1104 + X1204 + X1304 + X1404 + X1504 = 488.32
X2104 + X2204 + X2304 + X2404 + X2504 = 0.0
X3104 + X3204 + X3304 + X3404 + X3504 = 995.19
X4104 + X4204 + X4304 + X4404 + X4504 = 6092.65
X1105 + X1205 + X1305 + X1405 + X1505 = 1785.83
X2105 + X2205 + X2305 + X2405 + X2505 = 0.0
X3105 + X3205 + X3305 + X3405 + X3505 = 2518.15
X4105 + X4205 + X4305 + X4405 + X4505 = 12781.22
X1106 + X1206 + X1306 + X1406 + X1506 = 25.21
X2106 + X2206 + X2306 + X2406 + X2506 = 0.0
X3106 + X3206 + X3306 + X3406 + X3506 = 181.21
X4106 + X4206 + X4306 + X4406 + X4506 = 1346.29
X1107 + X1207 + X1307 + X1407 + X1507 = 2400.99
X2107 + X2207 + X2307 + X2407 + X2507 = 0.0
X3107 + X3207 + X3307 + X3407 + X3507 = 4994.38
X4107 + X4207 + X4307 + X4407 + X4507 = 19091.96
X1108 + X1208 + X1308 + X1408 + X1508 = 58.27
X2108 + X2208 + X2308 + X2408 + X2508 = 0.0
X3108 + X3208 + X3308 + X3408 + X3508 = 153.74
X4108 + X4208 + X4308 + X4408 + X4508 = 286.83
X1109 + X1209 + X1309 + X1409 + X1509 = 301.55
X2109 + X2209 + X2309 + X2409 + X2509 = 0.0
X3109 + X3209 + X3309 + X3409 + X3509 = 1494.70
X4109 + X4209 + X4309 + X4409 + X4509 = 3546.13
X1110 + X1210 + X1310 + X1410 + X1510 = 992.04
X2110 + X2210 + X2310 + X2410 + X2510 = 0.0
X3110 + X3210 + X3310 + X3410 + X3510 = 2452.86
```

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X4110 + X4210 + X4310 + X4410 + X4510 = 5164.03
X1111 + X1211 + X1311 + X1411 + X1511 = 451.47
X2111 + X2211 + X2311 + X2411 + X2511 = 0.0
X3111 + X3211 + X3311 + X3411 + X3511 = 613.53
X4111 + X4211 + X4311 + X4411 + X4511 = 2019.61
.000050X1101 + .000050X1102 + .000050X1103 + .000050X1104 +
.000050X1105 + .000050X1106 + .000050X1107 + .000050X1108 +
.000050X1109 + .000050X1110 + .000050X1111 +
.000050X2101 + .000050X2102 + .000050X2103 + .000050X2104 +
.000050X2105 + .000050X2106 + .000050X2107 + .000050X2108 +
.000050X2109 + .000050X2110 + .000050X2111 +
.000050X3101 + .000050X3102 + .000050X3103 + .000050X3104 +
.000050X3105 + .000050X3106 + .000050X3107 + .000050X3108 +
.000050X3109 + .000050X3110 + .000050X3111 +
.000050X4101 + .000050X4102 + .000050X4103 + .000050X4104 +
.000050X4105 + .000050X4106 + .000050X4107 + .000050X4108 +
.000050X4109 + .000050X4110 + .000050X4111 - ADP1 .LE. 0.0
.000050X1201 + .000050X1202 + .000050X1203 + .000050X1204 +
.000050X1205 + .000050X1206 + .000050X1207 + .000050X1208 +
.000050X1209 + .000050X1210 + .000050X1211 +
.000050X2201 + .000050X2202 + .000050X2203 + .000050X2204 +
.000050X2205 + .000050X2206 + .000050X2207 + .000050X2208 +
.000050X2209 + .000050X2210 + .000050X2211 +
.000050X3201 + .000050X3202 + .000050X3203 + .000050X3204 +
.000050X3205 + .000050X3206 + .000050X3207 + .000050X3208 +
.000050X3209 + .000050X3210 + .000050X3211 +
.000050X4201 + .000050X4202 + .000050X4203 + .000050X4204 +
.000050X4205 + .000050X4206 + .000050X4207 + .000050X4208 +
.000050X4209 + .000050X4210 + .000050X4211 - ADP2 .LE. 0.0
.000050X1301 + .000050X1302 + .000050X1303 + .000050X1304 +
.000050X1305 + .000050X1306 + .000050X1307 + .000050X1308 +
.000050X1309 + .000050X1310 + .000050X1311 +
.000050X2301 + .000050X2302 + .000050X2303 + .000050X2304 +
.000050X2305 + .000050X2306 + .000050X2307 + .000050X2308 +
.000050X2309 + .000050X2310 + .000050X2311 +
.000050X3301 + .000050X3302 + .000050X3303 + .000050X3304 +
.000050X3305 + .000050X3306 + .000050X3307 + .000050X3308 +
.000050X3309 + .000050X3310 + .000050X3311 +
.000050X4301 + .000050X4302 + .000050X4303 + .000050X4304 +
.000050X4305 + .000050X4306 + .000050X4307 + .000050X4308 +
.000050X4309 + .000050X4310 + .000050X4311 - ADP3 .LE. 0.0
.000050X1401 + .000050X1402 + .000050X1403 + .000050X1404 +
.000050X1405 + .000050X1406 + .000050X1407 + .000050X1408 +
.000050X1409 + .000050X1410 + .000050X1411 +
.000050X2401 + .000050X2402 + .000050X2403 + .000050X2404 +
.000050X2405 + .000050X2406 + .000050X2407 + .000050X2408 +
.000050X2409 + .000050X2410 + .000050X2411 +
.000050X3401 + .000050X3402 + .000050X3403 + .000050X3404 +
.000050X3405 + .000050X3406 + .000050X3407 + .000050X3408 +
.000050X3409 + .000050X3410 + .000050X3411 +
.000050X4401 + .000050X4402 + .000050X4403 + .000050X4404 +
.000050X4405 + .000050X4406 + .000050X4407 + .000050X4408 +
.000050X4409 + .000050X4410 + .000050X4411 - ADP4 .LE. 0.0
.000050X1501 + .000050X1502 + .000050X1503 + .000050X1504 +
.000050X1505 + .000050X1506 + .000050X1507 + .000050X1508 +
.000050X1509 + .000050X1510 + .000050X1511 +
.000050X2501 + .000050X2502 + .000050X2503 + .000050X2504 +
.000050X2505 + .000050X2506 + .000050X2507 + .000050X2508 +
.000050X2509 + .000050X2510 + .000050X2511 +
.000050X3501 + .000050X3502 + .000050X3503 + .000050X3504 +
.000050X3505 + .000050X3506 + .000050X3507 + .000050X3508 +
.000050X3509 + .000050X3510 + .000050X3511 +
.000050X4501 + .000050X4502 + .000050X4503 + .000050X4504 +
.000050X4505 + .000050X4506 + .000050X4507 + .000050X4508 +
.000050X4509 + .000050X4510 + .000050X4511 - ADP5 .LE. 0.0
```

```
.0231X1101 + .0231X1102 + .0231X1103 + .0231X1104 +
.0231X1105 + .0231X1106 + .0231X1107 + .0231X1108 +
.0231X1109 + .0231X1110 + .0231X1111 +
.0231X2101 + .0231X2102 + .0231X2103 + .0231X2104 +
.0231X2105 + .0231X2106 + .0231X2107 + .0231X2108 +
.0231X2109 + .0231X2110 + .0231X2111 +
.0231X3101 + .0231X3102 + .0231X3103 + .0231X3104 +
.0231X3105 + .0231X3106 + .0231X3107 + .0231X3108 +
.0231X3109 + .0231X3110 + .0231X3111 +
.0231X4101 + .0231X4102 + .0231X4103 + .0231X4104 +
.0231X4105 + .0231X4106 + .0231X4107 + .0231X4108 +
.0231X4109 + .0231X4110 + .0231X4111 - PT1 - PH1 .LE. 0.0
.0231X1201 + .0231X1202 + .0231X1203 + .0231X1204 +
.0231X1205 + .0231X1206 + .0231X1207 + .0231X1208 +
.0231X1209 + .0231X1210 + .0231X1211 +
.0231X2201 + .0231X2202 + .0231X2203 + .0231X2204 +
.0231X2205 + .0231X2206 + .0231X2207 + .0231X2208 +
.0231X2209 + .0231X2210 + .0231X2211 +
.0231X3201 + .0231X3202 + .0231X3203 + .0231X3204 +
.0231X3205 + .0231X3206 + .0231X3207 + .0231X3208 +
.0231X3209 + .0231X3210 + .0231X3211 +
.0231X4201 + .0231X4202 + .0231X4203 + .0231X4204 +
.0231X4205 + .0231X4206 + .0231X4207 + .0231X4208 +
.0231X4209 + .0231X4210 + .0231X4211 - PT2 - PH2 .LE. 0.0
.0231X1301 + .0231X1302 + .0231X1303 + .0231X1304 +
.0231X1305 + .0231X1306 + .0231X1307 + .0231X1308 +
.0231X1309 + .0231X1310 + .0231X1311 +
.0231X2301 + .0231X2302 + .0231X2303 + .0231X2304 +
.0231X2305 + .0231X2306 + .0231X2307 + .0231X2308 +
.0231X2309 + .0231X2310 + .0231X2311 +
.0231X3301 + .0231X3302 + .0231X3303 + .0231X3304 +
.0231X3305 + .0231X3306 + .0231X3307 + .0231X3308 +
.0231X3309 + .0231X3310 + .0231X3311 +
.0231X4301 + .0231X4302 + .0231X4303 + .0231X4304 +
.0231X4305 + .0231X4306 + .0231X4307 + .0231X4308 +
.0231X4309 + .0231X4310 + .0231X4311 - PT3 - PH3 .LE. 0.0
.0231X1401 + .0231X1402 + .0231X1403 + .0231X1404 +
.0231X1405 + .0231X1406 + .0231X1407 + .0231X1408 +
.0231X1409 + .0231X1410 + .0231X1411 +
.0231X2401 + .0231X2402 + .0231X2403 + .0231X2404 +
.0231X2405 + .0231X2406 + .0231X2407 + .0231X2408 +
.0231X2409 + .0231X2410 + .0231X2411 +
.0231X3401 + .0231X3402 + .0231X3403 + .0231X3404 +
.0231X3405 + .0231X3406 + .0231X3407 + .0231X3408 +
.0231X3409 + .0231X3410 + .0231X3411 +
.0231X4401 + .0231X4402 + .0231X4403 + .0231X4404 +
.0231X4405 + .0231X4406 + .0231X4407 + .0231X4408 +
.0231X4409 + .0231X4410 + .0231X4411 - PT4 - PH4 .LE. 0.0
.0231X1501 + .0231X1502 + .0231X1503 + .0231X1504 +
.0231X1505 + .0231X1506 + .0231X1507 + .0231X1508 +
.0231X1509 + .0231X1510 + .0231X1511 +
.0231X2501 + .0231X2502 + .0231X2503 + .0231X2504 +
.0231X2505 + .0231X2506 + .0231X2507 + .0231X2508 +
.0231X2509 + .0231X2510 + .0231X2511 +
.0231X3501 + .0231X3502 + .0231X3503 + .0231X3504 +
.0231X3505 + .0231X3506 + .0231X3507 + .0231X3508 +
.0231X3509 + .0231X3510 + .0231X3511 +
.0231X4501 + .0231X4502 + .0231X4503 + .0231X4504 +
.0231X4505 + .0231X4506 + .0231X4507 + .0231X4508 +
.0231X4509 + .0231X4510 + .0231X4511 - PT5 - PH5 .LE. 0.0
20.750X1101 + 20.750X1102 + 20.750X1103 + 20.750X1104 +
20.750X1105 + 20.750X1106 + 20.750X1107 + 20.750X1108 +
20.750X1109 + 20.750X1110 + 20.750X1111 +
20.750X2101 + 20.750X2102 + 20.750X2103 + 20.750X2104 +
20.750X2105 + 20.750X2106 + 20.750X2107 + 20.750X2108 +
```

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20.750X2109 + 20.750X2110 + 20.750X2111 +
20.750X3101 + 20.750X3102 + 20.750X3103 + 20.750X3104 +
20.750X3105 + 20.750X3106 + 20.750X3107 + 20.750X3108 +
20.750X3109 + 20.750X3110 + 20.750X3111 +
20.750X4101 + 20.750X4102 + 20.750X4103 + 20.750X4104 +
20.750X4105 + 20.750X4106 + 20.750X4107 + 20.750X4108 +
20.750X4109 + 20.750X4110 + 20.750X4111 - 120000SP1 -
120000SP6 .LE. 0.0
20.750X1201 + 20.750X1202 + 20.750X1203 + 20.750X1204 +
20.750X1205 + 20.750X1206 + 20.750X1207 + 20.750X1208 +
20.750X1209 + 20.750X1210 + 20.750X1211 +
20.750X2201 + 20.750X2202 + 20.750X2203 + 20.750X2204 +
20.750X2205 + 20.750X2206 + 20.750X2207 + 20.750X2208 +
20.750X2209 + 20.750X2210 + 20.750X2211 +
20.750X3201 + 20.750X3202 + 20.750X3203 + 20.750X3204 +
20.750X3205 + 20.750X3206 + 20.750X3207 + 20.750X3208 +
20.750X3209 + 20.750X3210 + 20.750X3211 +
20.750X4201 + 20.750X4202 + 20.750X4203 + 20.750X4204 +
20.750X4205 + 20.750X4206 + 20.750X4207 + 20.750X4208 +
20.750X4209 + 20.750X4210 + 20.750X4211 - 120000SP2 -
120000SP7 .LE. 55950.0
20.750X1301 + 20.750X1302 + 20.750X1303 + 20.750X1304 +
20.750X1305 + 20.750X1306 + 20.750X1307 + 20.750X1308 +
20.750X1309 + 20.750X1310 + 20.750X1311 +
20.750X2301 + 20.750X2302 + 20.750X2303 + 20.750X2304 +
20.750X2305 + 20.750X2306 + 20.750X2307 + 20.750X2308 +
20.750X2309 + 20.750X2310 + 20.750X2311 +
20.750X3301 + 20.750X3302 + 20.750X3303 + 20.750X3304 +
20.750X3305 + 20.750X3306 + 20.750X3307 + 20.750X3308 +
20.750X3309 + 20.750X3310 + 20.750X3311 +
20.750X4301 + 20.750X4302 + 20.750X4303 + 20.750X4304 +
20.750X4305 + 20.750X4306 + 20.750X4307 + 20.750X4308 +
20.750X4309 + 20.750X4310 + 20.750X4311 - 120000SP3 -
120000SP8 .LE. 8600.0
20.750X1401 + 20.750X1402 + 20.750X1403 + 20.750X1404 +
20.750X1405 + 20.750X1406 + 20.750X1407 + 20.750X1408 +
20.750X1409 + 20.750X1410 + 20.750X1411 +
20.750X2401 + 20.750X2402 + 20.750X2403 + 20.750X2404 +
20.750X2405 + 20.750X2406 + 20.750X2407 + 20.750X2408 +
20.750X2409 + 20.750X2410 + 20.750X2411 +
20.750X3401 + 20.750X3402 + 20.750X3403 + 20.750X3404 +
20.750X3405 + 20.750X3406 + 20.750X3407 + 20.750X3408 +
20.750X3409 + 20.750X3410 + 20.750X3411 +
20.750X4401 + 20.750X4402 + 20.750X4403 + 20.750X4404 +
20.750X4405 + 20.750X4406 + 20.750X4407 + 20.750X4408 +
20.750X4409 + 20.750X4410 + 20.750X4411 - 120000SP4 -
120000SP9 .LE. 488200.0
20.750X1501 + 20.750X1502 + 20.750X1503 + 20.750X1504 +
20.750X1505 + 20.750X1506 + 20.750X1507 + 20.750X1508 +
20.750X1509 + 20.750X1510 + 20.750X1511 +
20.750X2501 + 20.750X2502 + 20.750X2503 + 20.750X2504 +
20.750X2505 + 20.750X2506 + 20.750X2507 + 20.750X2508 +
20.750X2509 + 20.750X2510 + 20.750X2511 +
20.750X3501 + 20.750X3502 + 20.750X3503 + 20.750X3504 +
20.750X3505 + 20.750X3506 + 20.750X3507 + 20.750X3508 +
20.750X3509 + 20.750X3510 + 20.750X3511 +
20.750X4501 + 20.750X4502 + 20.750X4503 + 20.750X4504 +
20.750X4505 + 20.750X4506 + 20.750X4507 + 20.750X4508 +
20.750X4509 + 20.750X4510 + 20.750X4511 - 120000SP5 -
120000SP10 .LE. 48800.0
PT1 + PT2 + PT3 + PT4 + PT5 .EQ. 458
X1101 + X1102 + X1103 + X1104 + X1105 + X1106 + X1107 +
X1108 + X1109 + X1110 + X1111 .LE. 8786.38
X2101 + X2102 + X2103 + X2104 + X2105 + X2106 + X2107 +
X2108 + X2109 + X2110 + X2111 .LE. 0.0
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X3101 + X3102 + X3103 + X3104 + X3105 + X3106 + X3107 +
X3108 + X3109 + X3110 + X3111 .LE. 20339.14
X4101 + X4102 + X4103 + X4104 + X4105 + X4106 + X4107 +
X4108 + X4109 + X4110 + X4111 .LE. 69897.97
X2201 + X2202 + X2203 + X2204 + X2205 + X2206 + X2207 +
X2208 + X2209 + X2210 + X2211 .LE. 0.0
X4201 + X4202 + X4203 + X4204 + X4205 + X4206 + X4207 +
X4208 + X4209 + X4210 + X4211 .LE. 69897.97
X1301 + X1302 + X1303 + X1304 + X1305 + X1306 + X1307 +
X1308 + X1309 + X1310 + X1311 .LE. 8786.38
X3301 + X3302 + X3303 + X3304 + X3305 + X3306 + X3307 +
X3308 + X3309 + X3310 + X3311 .LE. 20339.14
X1401 + X1402 + X1403 + X1404 + X1405 + X1406 + X1407 +
X1408 + X1409 + X1410 + X1411 .LE. 8786.38
X2401 + X2402 + X2403 + X2404 + X2405 + X2406 + X2407 +
X2408 + X2409 + X2410 + X2411 .LE. 0.0
X3401 + X3402 + X3403 + X3404 + X3405 + X3406 + X3407 +
X3408 + X3409 + X3410 + X3411 .LE. 20339.14
X4401 + X4402 + X4403 + X4404 + X4405 + X4406 + X4407 +
X4408 + X4409 + X4410 + X4411 .LE. 69897.97
X1501 + X1502 + X1503 + X1504 + X1505 + X1506 + X1507 +
X1508 + X1509 + X1510 + X1511 .LE. 8786.38
X2501 + X2502 + X2503 + X2504 + X2505 + X2506 + X2507 +
X2508 + X2509 + X2510 + X2511 .LE. 0.0
X3501 + X3502 + X3503 + X3504 + X3505 + X3506 + X3507 +
X3508 + X3509 + X3510 + X3511 .LE. 20339.14
X4501 + X4502 + X4503 + X4504 + X4505 + X4506 + X4507 +
X4508 + X4509 + X4510 + X4511 .LE. 69897.97
SP1 + SP2 + SP3 + SP4 + SP5 + SP6 + SP7 +
SP8 + SP9 + SP10 .LE. 20.0
ADP1 + ADP2 + ADP3 + ADP4 + ADP5 .LE. 5.0
RNGOBJ
RNGRHS
PRINT
CHECK
OPTIMIZE
STOP
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This research enhances the Defense Logistics Agency planning process by developing two emergency planning models. These models are macro-models of the inventory control point system and the depot system. If a natural disaster or sabotage destroyed an entire facility during peace time, these models would provide insight into what realignment actions would have to occur and the potential magnitude of the actions. The model results would be used in conjunction with other essential information in the decision making process.

Both models are formulated as linear programming models. The primary objective is to minimize the cost of realigning the systems. Both personnel and material resources are considered. The Northwestern University Multi-Purpose Optimization System is used to program the models. The sensitivity of the models is examined in detail.

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